School of Design and Art

Department of Design

A Creative Journey

developing an

Integrated High-Fashion Knitwear Development Process

using

Computerized Seamless V-bed Knitting Systems

Sooyung Yang

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material that has been previously accepted for the award of any other degree or diploma in any university.

Signature: Sooyung Yang

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Abstract

This PhD applied a participatory action research approach to address the organizational problems that compromise the use of computerized seamless V-bed knitwear systems in the high-fashion knitwear sector. The research is a response to a widely acknowledged conflict between high-fashion design processes and processes by which designs are developed on computerized seamless V-bed knitting systems. The social, organizational, and technical aspects of design and manufacturing using computerized seamless V-bed knitting technology in high-fashion knitwear design were analyzed as a socio-technical system (STS). This approach led to a review of the workflows, tasks and roles; identifying and testing new design and manufacturing processes, design methods, and garment solutions; creating a theory model of a new integrated design process; and developing and testing new design processes, design methods, and fashion design education courses that teach these new fashion knitwear approaches.

The research was undertaken using a Shima Seiki WholeGarment® system, a current computerized seamless V-bed knitting design and manufacturing technology. The studio workspace, yarn, use of the Shima Seiki system; involvement in fashion projects, and associate supervision were provided by the Department of Agriculture and Food Western Australia (DAFWA).

The research demonstrated a high-fashion knitwear designer can undertake all aspects of managing computerized seamless V-bed knitwear design and production to the completion of *1st sample*, the first successful sample of a new fabric or garment, was produced using the computer knit data. This finding was developed into a new integrated design process and design methods that remove most of the problems of computerized seamless V-bed knitting systems in high-fashion and offers additional benefits including reduction in time to market and design costs, and increases in the creative solution space for high-fashion knitwear design.

The researcher has called this new role, a 'designer-interpreter' to denote a professional knitwear designer with additional training in managing computerized seamless knitting machines. Within the context of 'designer-interpreter', this research also established the feasibility of a new form of a 'post-industrial craft-based one-person knitwear production system'.

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Glossary

The following lists technical terms/expressions used in this study. Definitions are sourced from Answers Corporation (2008), Black (2002), Calasibetta (1988), Carr & Pomeroy (1992), Choi & Powell (2005), Eckert & Stacey (1994), Hatch (1993), Lee et al. (2002), Pizzuto et al. (1980), Shima Seiki Mfg. (2008), Spencer & Knovel (Firm) (2001), Stecker (1996), and Wilson (2008).

1st sample

1st sample is known as 'toile' in fashion design, but there is no specific name for it in knitwear design. It is described as *1st sample* fabric or garment knitted with the 'real' yarn.

Actual knitting

This term is used as the opposite of 'virtual knitting' in this thesis and refers to knitting with real yarn on the knitting machine.

Alta Roma & AltaRomAltaModa

In 1998, the Agenzia per la Moda SpA, a company founded to promote the city of Rome on the Italian High-fashion circuit, was created by the Rome Chamber of Commerce and the Muncipality of Rome.

In 2001, the Agenzia per la Moda was transformed into Alta Roma SpA. by the entry of high profile private partners. Resources were increased and activities were extended to include a reformulation of the economic potential of the fashion sector in Rome. AltaRoma's activities are focused not only on maximizing the potential of Rome's fashion but also on promoting and further strengthening the activities of those players who represent creativity, style, and tradition.

The main event organized by AltaRoma is AltaRomAltaModa, which coincides with the two annual appointments of Roman fashion week, in January and in July.

Combinatorics

Combinatorics is part of the science of counting. It is deduced from simple principles and helps solve counting problems. Combinatorics combines general techniques such as permutations, combinations, possibility trees, and factorials.

DAFWA

<u>D</u>epartment of <u>A</u>griculture <u>F</u>ood <u>W</u>estern <u>A</u>ustralia

Design specifications sheet

The *design specifications sheet* is a document that a knitwear designer creates to communicate with others involved in the sample manufacturing and production process of a garment. The quality of the design as merchandise depends on how the knitwear designer effectively conveys her/his ideas by means of the design specifications.

To produce the *design specifications sheet*, technical fashion drawings, known in the industry as 'flats' are used. The 'flats' visually communicate design information, as well as provide information to the sample and production make-up staff. The drawing of flats does not need artistic skills, but it does require accuracy in proportioning sizes.

The *design specifications sheet* also contains the design details, including fabrics, trims, special treatments and construction notes.

Draping

One of the required skills for fashion designers is to sculpt cloth on the body into designs of beautiful shapes that honor both the cloth and the body. Designers create garment patterns with fit and proportion - but also assess the garment shapes with their hands, eyes, and mind to develop unique and creative designs. Some fashion designers regard draping as the most pure method of apparel design, in that what you see is what you get: no sketching or pattern drafting is necessary. It is also considered three-dimensional patternmaking, whereas flat-patternmaking is two-dimensional, and done primarily in high-priced fashion houses. The draping method is also used for more elaborate and unique designs that are hard to obtain through the flat pattern method. This is because it is nearly impossible to account for the way a fabric will drape or hang on the body without an actual 3-dimensional test run. It involves creating a muslin mock-up pattern by pinning fabric directly on a dress form, then transferring the muslin outline and markings onto a paper pattern or using the muslin as the pattern itself.

Ease

'Ease' is the amount of fabric allowed in the pattern design to accommodate body movement, for instance, on the back shoulder seam, across shoulder blades, across bustline; at waistline of bodice, pants, and skirt, and across hipline of garment.

Extreme fashion

'Extreme fashion' refers to garment designs that are exaggerated beyond orthodox styles, thus providing extra ordinary looks.

Fast fashion

'Fast Fashion' is a term used to describe clothing collections based on the philosophy of quick manufacturing at an affordable price with rapid response to market demand.

Flat-patternmaking

In sewing and fashion design, a pattern is an original garment from which other garments of a similar style are copied, or the paper or cardboard templates from which the parts of a garment are traced onto fabric before cutting out and assembling (sometimes called paper patterns). Patternmaking or pattern cutting is the art of designing patterns. A custom-fitted basic pattern from which patterns for many different styles can be created is called a sloper or block.

Fully-fashioned

The term 'fully-fashioned' refers to when knitted fabric is knitted in the same pattern shapes as would be cut from flat fabric for example; front body, back body, and sleeves. Currently, it is the most popular of the five types of knitwear production: fully-cut; garment length knitting; fully-fashioned; integral garment knitting; and seamless knitting.

There is almost no loss of fabric in fully-fashioned knitting but the knitting process is too difficult for fast production. Fully-fashioned knitting is being replaced worldwide by seamless knitting technology (see below), which addressed many of its problems. WholeGarment® is Shima Seiki's seamless knitting technology.

Garment shape

An outline or silhouette of the garment. The shoulder line, the waistline, and the hemline are the basic elements of forming a garment shape.

High-fashion knitwear

The latest trend setting fashion or design, usually intended for or adopted by an exclusive clientele. The term is applied also to higher-priced knitted garments.

Knit data

In this thesis, the term ‘knit data’ refers to the two different types of file created by the Shima SDS-ONE® CAD system to produce a fabric or garment on the knitting machine.

Knitter

‘Knitters’ refer to the workers who drive the industrial knitting machines manually, or whose duties are responsible for running groups of them.

Knitting machine operator

‘Knitting machine operators’ refer to the workers whose duties are more around running electronic and automated knitting machines. Almost entirely male, but researcher had been able to work with a female knitting machine operator for a few years who was a knitter for a manual single flat bed knitting machine.

Knitting machine technician

In this thesis, ‘knitting machine technicians’ refer to the workers who either prepare knitting specifications sheets for the knitters to run industrial knitting machines or program sets of data for automated knitting machines. They are almost all male and usually older. They tend to stay at one company for a long time, often for their entire career.

Knitting technologists

In this thesis, the term ‘knitting technologist’ is used to refer to both knitting machine operator and knitting machine technician.

Knitwear design

Knitwear design is ‘creating design specifications for the manufacturer of knitted garments’. Knitwear design can be viewed as an intersection of two domains; fashion design and textile design, and also can be regarded as a union of those two domains.

Knitwear designer

Job specifications of knitwear designers vary between manufacturers. In most cases, knitwear designers have more than double the workload of other fashion designers for each garment because they have to design the knitted fabrics, create the garment shapes, and also program the computerized industrial knitting machines. They are almost always young and female. The average time they remain with one employer is about three years.

Machine data

‘Machine data’ refer to several types of data that are needed to operate the knitting machine via the controller console.

Production make-up staff

The production make-up employees comprise garment cutters, people who operate various kinds of industrial sewing machines, for example, linker machines and over-lockers.

Production manager

Production manager generally handle routine logistics such as production planning, scheduling, control, and garment costing. Their duties may vary or slightly differ from a company to another. Some of production managers are promoted from within the company. Very few managers are former designers or technicians. Consequently, in some cases, production is managed by people lacking a detailed first hand understanding of the garment design and production process. Conversely, very few designers have the ability and personality to be managers.

Prototype

In this paper, prototype is used to describe an early and typical example of a fabric swatch or garment before *1st sample*. The action of doing many sample rounds to develop *1st sample* is also known as prototyping. Prototypes typically use cheaper yarn that works well with the knitting machine, for example, acrylic yarn.

Sampling make-up staff

Almost entirely female. They are usually recruited by promoting the most able production make-up workers. They exhibit high skills in relation to knowledge and construction of garment, but lower speed skills. They generally carry out garment assembly operation as well as preparatory and finishing work such as over-locking and pressing.

Seamless technology

Refers to the knitting technology that creates one entire complete garment thus eliminating garment make-up processes, such as cutting and sewing and some pattern-making processes. Shima Seiki in Japan and Stoll in Germany are two leading manufacturers of computerized seamless V-bed knitting machines.

Stitch structure

Each loop in a knitted fabric is a stitch, thus a stitch structure is the arrangement of stitches in a knitted fabric.

Stitch pattern

Refers to knitted fabric texture that is composed of repetition of ‘one complete design’ unit of knit stitch sequences.

Virtual knitting

The 3 dimensional simulation of knitted fabric or garment with pseudo yarn on the CAD system.

Warp knitting

Warp knitting is a relatively uncommon type of knitting in which yarns run the length of the fabric rather than from side-to-side. The yarns form a loop in one course and then move diagonally to the next wale in the following course. The yarns zigzag diagonally along the length of the fabric. Each stitch in a course is made by a different yarn.

Weft knitting

Weft knitting is the most common, the ‘normal’ type of knitting in which yarns run from side-to-side, across the width of the fabric. The fabric is actually formed by manipulating the knitting needles to make loops in horizontal courses built one on top of another. The stitches in a course are made by a single yarn.

WholeGarment® knitting system

System of Shima Seiki’s line of machines that are capable of seamless knitting. It is integrated SDS®-ONE CAD system that supports all the phases of plan, design, evaluation, and production. A similar system from Stoll is called ‘Knit and Wear®’.

Fabric/garment images provided by DAFWA used in the thesis

Figure 11: Tube garment.

Project name	Tube sessions 2007
Project supporters	DAFWA & Curtin University of Technology
Course coordinator	Anne Farren
Design consultant	Sooyung Yang
Garment designers	Roisin Phelan & Yuliana Wirawan
Garment programmer	Sooyung Yang
Model	Caitlain Farren
Photographer	Penny Lane

Figure 61: Garment using modified tube template with slashes and slits.

Project name	Tube sessions 2008
Project supporters	DAFWA & Curtin University of Technology
Course coordinator	Anne Farren
Design consultant	Sooyung Yang
Garment designers	Kimberley Gouges & Eleasha Anderson Erin Larkin & Libby West
Garment programmer	Sooyung Yang
Models	Georgia
Photographer	Penny Lane

Figure 62: High-fashion garment created using garment elements combined using S•Paint image software.

Project name	Tube sessions 2008
Project supporters	DAFWA & Curtin University of Technology
Course coordinator	Anne Farren
Design consultant	Sooyung Yang
Garment designers	LAI Hiu Kwan (Kwan) & Wong Hoi Ki (Hidy)
Garment programmer	Sooyung Yang
Models	Maychoon Cheah, Caitlain Farren, & Georgia
Photographer	Penny Lane

Figure 68: Examples of different silhouettes of the same garment on two different models.

Project name	Tube sessions 2007
Project supporters	DAFWA & Curtin University of Technology
Course coordinator	Anne Farren
Design consultant	Sooyung Yang
Garment designers (clockwise)	Alexi Alcroft, Rasha Karim, & Prim Clarke
Garment programmer	Sooyung Yang
Models	Maychoon Cheah & Caitlain Farren
Photographer	Penny Lane

Figure 74: Examples of the use of the ‘tube’, slash and slit garment structure.

Project name	Tube sessions 2008
Project supporters	DAFWA & Curtin University of Technology
Course coordinator	Anne Farren

Design consultant	Sooyung Yang
Garment designers (left to right)	Pheobe McCarthy & Louwellyn Gossi Aranee Poolsanat Alexi Alcroft, Rasha Karim, & Prim Clarke
Garment programmer	Sooyung Yang
Models	Maychoon Cheah, Caitlain Farren, & Georgia
Photographer	Penny Lane

Figure 78: Examples of fabrics and garments using combinations of design methods.

Project name	Tube sessions 2009
Project supporters	DAFWA & Curtin University of Technology
Course coordinator	Anne Farren
Design consultant	Sooyung Yang
Garment designers (left to right)	Jennifer Nebel, Candice Tranchita & Sally Wilson Wai Han (Elsie) Wong & Yee Wing (Eraine) Poon
Garment programmer	Sooyung Yang
Model	N/A
Photographer	Penny Lane

Figure 79: Outcome of trial and error.

Project name	'Design for Comfort'
Project supporter	DAFWA
Chief Investigators	Suzette Worden & Anne Farren
Fabric design consultant	Sooyung Yang
Fabric programmer	Sooyung Yang
Photographer	Ashley de Prazer

Figure 83: Examples of garments created by five Western Australian designers.

Project name	'Design for Comfort'
Project supporter	DAFWA
Chief Investigators	Suzette Worden & Anne Farren
Fabric designer	Sooyung Yang
Garment designers (left to right)	Ray Costarella Rebecca Paterson Megan salmon Louise Snook Melissa yap
Fabric programmer	Sooyung Yang
Photographer	Ashley de Prazer

Figure 94: Examples of knitted garments developed by students in 2007 using slashes and slits in tube-derived garment shapes designed and knitted using the researchers new knitwear design approach.

Project name	Tube sessions 2007
Project supporters	DAFWA & Curtin University of Technology
Course coordinator	Anne Farren
Design consultant	Sooyung Yang
Garment designers (left to right)	Madeleine Tucker & Jessica Amato & Emily Gecas Sam Elmslie & Sarah Afleck
Garment programmer	Sooyung Yang

Models	Maychoon Cheah
Photographer	Penny Lane

Figure 95: Miniature WholeGarment® dresses.

Project name	Professional Practicum 390 at Curtin
Project supporter	DAFWA
Garment programmer	Sooyung Yang
Garment design consultant	Sooyung Yang
Garment embellishment designer	Aranee Poolsawat
Photographer	Penny Lane

Figure 96: The dancers in their moves.

Project name	Dance performance at the Livestock Updates 2008
Project supporter	DAFWA
Garment design consultant	Sooyung Yang
Garment designers	Yasmin Kopij, Hayley Barsden, & Ella Garland Madeleine Tucker, Jessica Amato, & Emily Gecas Roisin Phelan Yvonne Wuriwen Pheobe McCarthy & Louwellyn Gossi Yuliana Wirawan Alexi Alcroft, Rasha Karim, & Prim Clarke Chloe Spalding & Jocelyn Tan Evelyn Teo & Angela Yung
Garment programmer	Sooyung Yang
Models	Elyse, Kelly, Kylie, Lucy, Sasha, & Sophie
Photographer	Sam Landels

Figure 100: Computerized seamless V-bed knitwear design and manufacturing technology knitted tubes with post-embellishment suitable for development in hand-framed knitting.

Project name	Professional Practicum 390 at Curtin
Project supporter	DAFWA
Garment programmer	Sooyung Yang
Garment design consultant	Sooyung Yang
Garment embellishment designer	Aranee Poolsawat
Photographer	Penny Lane

Figure 104: 'Full of accidental defects'.

Project name	'Design for Comfort'
Project supporter	DAFWA
Chief Investigators	Suzette Worden & Anne Farren
Fabric designer	Sooyung Yang
Fabric programmer	Sooyung Yang
Photographer	Ashley de Prazer

Figure 105: Imitation of dropped stitches.

Project name	'Design for Comfort'
Project supporter	DAFWA
Chief Investigators	Suzette Worden & Anne Farren
Fabric designer	Sooyung Yang

Fabric programmer	Sooyung Yang
Photographer	Ashley de Prazer

Figure 106: Knitted fabric translation of an indigenous art work.

Project name	'Design for Comfort'
Project supporter	DAFWA
Chief Investigators	Suzette Worden & Anne Farren
Fabric design consultant	Sooyung Yang
Fabric programmer	Sooyung Yang
Garment designer	Megan Salmon
Model	Caitlain Farren
Photographer	Ashley de Prazer

Figure 108: Realization of combined sand images.

Project name	'Design for Comfort'
Project supporter	DAFWA
Chief Investigators	Suzette Worden & Anne Farren
Fabric design consultant	Sooyung Yang
Fabric programmer	Sooyung Yang
Photographer	Ashley de Prazer

Figure 109: Re-establishment of a geometric stitch pattern.

Project name	'Design for Comfort'
Project supporter	DAFWA
Chief Investigators	Suzette Worden & Anne Farren
Fabric designer	Sooyung Yang
Fabric programmer	Sooyung Yang
Photographer	Ashley de Prazer

Figure 110: Jacket made from series of strips.

Project name	'Design for Comfort'
Project supporter	DAFWA
Chief Investigators	Suzette Worden & Anne Farren
Fabric designer	Sooyung Yang
Fabric programmer	Sooyung Yang
Garment designer	Melissa Yap
Photographer	Ashley de Prazer

Figure 120: Tubes with post-embellishment.

Project name	Professional Practicum 390 at Curtin
Project supporter	DAFWA
Garment programmer	Sooyung Yang
Garment design consultant	Sooyung Yang
Garment embellishment designer	Aranee Poolsawat
Photographer	Penny Lane

Figure 121: Call for 'Woolly Dancers'.

Project name	Dance performance at the Livestock Updates 2008
Project supporter	DAFWA

Garment design consultant	Sooyung Yang
Garment programmer	Sooyung Yang
Garment designers	Roisin Phelan & Yuliana Wirawan
Graphic designer	Amy Clarke
Photographer	Penny Lane

Figure 123: The performing dancers in their white tube outfits.

Project name	Dance performance at the Livestock Updates 2008
Project supporter	DAFWA
Garment design consultant	Sooyung Yang
Garment designers	Yasmin Kopij, Hayley Barsden, & Ella Garland Madeleine Tucker, Jessica Amato, & Emily Gecas Roisin Phelan Yvonne Wuriwen Pheobe McCarthy & Louwellyn Gossi Yuliana Wirawan Alexi Alcroft, Rasha Karim, & Prim Clarke Chloe Spalding & Jocelyn Tan Evelyn Teo & Angela Yung
Garment programmer	Sooyung Yang
Models	Elyse, Kelly, Kylie, Lucy, Sasha, & Sophie
Photographer	Sam Landels

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CHAPTER 1: Introduction

This participatory action research PhD addressed and resolved the significant problems of gaining the benefits of computerized seamless V-bed knitting technology for high-fashion knit wear design as distinct from retail mass-market clothing design. It did this through research that led to the development of a new high-fashion knitwear design process and workflow; a redefinition of the roles and tasks of the knitwear designer, knitting machine technician and knitting machine operator; the development of new design methods; and the development and evaluation of new fashion design courses and curricula.

The research process used a participatory action research approach on a variety of real world semi-commercial fashion design projects using a Shima Seiki WholeGarment® knitting system as a representative of the computerized seamless V-bed knitting technology. During the research, the researcher designed, programmed and knitted 531 pieces from 8 semi-commercial knitwear design projects accompanied by 18 studio activities. The researcher, in addition to her role as PhD candidate, participated in the research projects as a participant-observer in the practical professional roles of knitwear designer, knitting machine technician, knitting machine operator and university lecturer. The access to a Shima Seiki WholeGarment® design and manufacture system, provision of workspace and yarn, involvement in fashion projects and associate supervision was provided by the Department of Agriculture and Food Western Australia (DAFWA).

Thesis structure

This thesis is presented in thirteen chapters in five sections following Perry's 5 section thesis model (2002) plus references and appendices. The thesis contains thirty-nine (39) tables and one-hundred and thirty-two (132) figures, including those in appendices. A small number of figures are repeated in the thesis for clarity. The five thesis sections are as follows:

- *Section 1* comprises Chapter 1, which introduces the thesis and provides an executive summary of this PhD research. The chapter describes the research problem and three research questions that guided the research. The significance and the background context of the research are presented. The chapter outlines the theoretical perspective and research methodology (discussed in detail in Chapter 6) and also briefly describes how the research data collection and analysis were undertaken in conjunction with the candidate undertaking multiple semi-commercial real world knitwear design projects using computerized seamless V-bed knitwear design and manufacture system. These practical knitwear design projects are briefly described in relation to the research methodology. The chapter also outlines the main findings (new design process, design methods, workflow, roles and fashion design program) and their implications for the problem addressed by the research and for the international knitwear industry. The chapter concludes with a brief explanation of prior personal experiences in the researcher's earlier professional life that gave insights into the research problem and potential solutions.

- *Section 2* comprises four chapters (Chapters 2 to 5) that review relevant literature related to the research problem including overview of textile concepts, the history of knitting technology from hand knitting to computerized seamless V-bed knitting, a technical overview of an example of a computerized seamless V-bed knitwear design and manufacturing system (the Shima Seiki WholeGarment® system), and an analysis of workflows for computerized seamless V-bed knitwear design and manufacture.
- *Section 3* comprises Chapter 6 in which is described the theoretical perspective and research methodology that underpin the research along with the methods of data collection and analysis used in this research.
- *Section 4* comprises six chapters (Chapters 7 to 12) that describe the collated and analyzed data findings from applying the research methods described in the previous section. The raw data is available in the appendices. These research data and findings are described under the following chapter headings:

1. Introduction to findings and new integrated computerized seamless V-bed knitwear design and manufacture process;
2. Development of design methods that extend the creative performance envelope of computerized seamless V-bed knitting design and manufacture;
3. Shima Seiki's CAD system SDS-ONE® software interface;
4. Researcher's reflections on using computerized seamless V-bed knitting machine in high-fashion knitwear design projects;
5. Analysis of three formal training courses undertaken at Shima Seiki Total Design Center in Japan; and
6. Analysis of teaching five education programs involving the use of computerized seamless V-bed knitting system.

- *Section 5*, the concluding section, comprises Chapter 13 that describes and discusses how the findings described in the six chapters of the fourth section resolve the research problem. In addition, Section 5 discusses the implications of the research outcomes for educating fashion designers, for industry practice and for knitwear design commercial applications. Lastly, the chapter identifies future research projects and programs that emerged during the course of this PhD and in analysis of the implications of the findings.

Research problem: Overview

The focus of this PhD was to improve the design process for high-fashion knitwear design using computerized seamless V-bed knitwear design and manufacturing technology systems in a way that places fashion designers in control of the design process and resolves the conflicts between the three professional roles and processes in the conventional computerized seamless V-bed knitwear design and manufacturing process. Together these interventions are intended to offer the opportunity for increased access to the significant potential benefits of computerized seamless V-bed knitting systems in high-fashion knitwear design.

The use of computerized seamless V-bed knitting systems offers huge potential for the high-fashion knitwear design industry. A significant problem, however, in using computerized seamless V-bed knitting technology is that the conventional processes used with the computerized seamless V-bed knitting system do not work well for high-fashion design because of a lack of fit between the high-fashion design process and the processes by which the computerized seamless V-bed knitting machines are programmed and operated. The current direction of computerized seamless V-bed knitting technology development is to automate the fashion design aspect of knitwear production by reducing knitwear design to the selection of simple standardized knitted garments with a small range of garment styles combined with changes to details, decorations, colored images, and stitch patterns in the fabric. For the most part, these are intended to be chosen by a knitting machine technician rather than a knitwear designer. This lies in fundamental contradiction to high-fashion design with its development of unusual and extreme design outcomes and an emphasis on aesthetic experience rather than garment details being defined primarily by technical and production factors.

When explored in detail, the above research problem reveals a suite of problem issues. The way that computerized seamless V-bed knitting technology has been conceived and implemented in its processes, user interfaces, workflows, authority paths, information handovers and professional processes is problematic for high-fashion knitwear designers (Eckert, 2001; Eckert & Stacey, 1994; Eckert, Stacey, & Wiley, 1999). This negates many of the potentially significant benefits of computerized seamless V-bed knitting for the international high-fashion knitwear industry. From the researcher's experiences of professional involvement in the high-fashion knitwear design and from discussions with others in the knitwear industry over the last decade, these issues are widely acknowledged by high-fashion knitwear designers worldwide and seem tightly linked with problems in the knitted garment design ***process*** developed by the manufacturers of computerized seamless V-bed knitting technology.

These problems however, have only recently come to the attention of fashion design researchers (see, for example, (Eckert & Stacey, 1994; Sayer, Wilson, & Challis, 2006)). Similar problems occur across all the manufacturers of computerized seamless V-bed knitwear design and manufacture technology systems and relate primarily to failure to best include high-fashion designers in the design and manufacture process as a result of the technology. This suggests the problems relate to inappropriate socio-technical processes rather than the technology alone. This PhD research, therefore, focuses in the main on the literature relating to the socio-technical processes, professional practices, and systems and workflows of knitwear design and manufacture. When referring to specific technology details, the researcher references the technical details of the Shima Seiki NewSES-183S•WG WholeGarment® system, which is the system used in this research.

The promotional material of manufacturers of computerized seamless V-bed knitwear design and manufacturing systems, such as those of Shima Seiki, are targeted primarily at mass retail knitwear manufacturing and indicate also they are positioning their systems as the basis for mass customization (Shima Seiki Mfg., 2008d). For example, Shima Seiki's design process is based on simple selection from pre-existing garment patterns and details or, alternatively, by custom-programming by engineers. This approach, common across computerized knitwear systems, actively minimizes the role of the fashion designer and makes difficult any interaction between fashion designers and others involved as described later. This form of knitwear development process reduces garment design to either a simple selection in the automated mode of the knitting system in a small number of standardized garment shapes and decorations, or an engineering level manipulation of the knitting system software by engineers and knitting machine technicians. To draw a parallel with computer software, the choice is restricted to selecting from a restricted range of standard automated functions, or having to program the computer code manually. The overarching problem is lack of integration between classical high-fashion design processes and computerized seamless V-bed knitting systems' garment development processes.

High-fashion knitwear requires substantial designer input and considerable adjusting of the shape, drape, feel, and aesthetic of proposed garments until the intended design outcomes are achieved (Frings, 2002; Stecker, 1996). Typically these artistic forms of design outcome can be achieved only via the use of 'expert' technical modes of operation of computerized seamless V-bed knitwear systems in which knitting machine technicians and engineers program the computerized knitting machinery to produce these aesthetically unusual garment shapes. These kinds of garments are different to the standard garment shapes created in the automated mode. In this, a 'proper' role of the knitting machine technician would be to fulfill the role of the patternmaker in fully-fashioned and integral garment knitting. The current computerized seamless V-bed knitting garment development process, however, results in the high-fashion knitwear designer creating unusual garments being totally dependent on the computerized knitwear technicians who themselves act to change the garments in ways that reflect their technical considerations. From experience, this leads to a major problem with the knitwear design process because the knitwear designer and knitting machine technician do not have the same shared knitwear design culture and knowledge as is shared between fashion designer and patternmaker in conventional fashion design processes. These problems, and the limited attempt to resolve them on the computerized seamless V-bed knitwear manufacturers' side by reducing fashion knitwear design to technology and the selection from a limited range of garment shapes, result in the high-fashion knitwear designer being effectively excluded from the computerized seamless V-bed knitwear garment development process. The result is that the benefits of computerized seamless V-bed knitting technology are not extended to high-fashion or 'Fast Fashion' arenas in the knitwear industry: innovative design improvement and styles in retail knitwear using the computerized seamless V-bed knitting technology is stifled.

The fact that the computerized seamless V-bed knitwear manufacturers' garment development processes do not make use of the expertise of high-fashion knitwear designers is a problem on several fronts and has multiple causes relating to the ways that the different design and manufacturing roles have been defined. The primary role and focus of knitting machine technicians are in maximizing production output rather than spending time creating samples for knitwear designers (Eckert, 2001; Eckert & Stacey, 1994; Eckert et al., 1999). This makes design and sample production problematic for the high-fashion knitwear designer. Knitting machine technicians commonly compromise fashion knitwear designers' aesthetic intentions for a garment by redesigning the garment to make it easier to program and faster or cheaper to knit (Eckert et al., 1999). Instead of the knitting machine technician being dedicated to the designer and the aesthetic success of a garment design, in the manner of a patternmaker in conventional fully-cut knitwear design, their focus is primarily efficient maximum use of the knitting machinery.

The problems are compounded by the ways that the formation of the roles and tasks and the education to support them have resulted in significant cultural differences between high-fashion knitwear designers and knitting machine technicians that make effective design and management communication between them difficult (Eckert, 2001). Most fashion knitwear designers are female and educated in Departments of Art and Design. The knitting machine technicians who program computerized seamless V-bed knitting machines are predominately male, operate within an engineering tradition, are usually trained up from being knitting machine operators through in-house training schemes at large knitwear companies after being recruited straight from school (Eckert & Stacey, 1994). The third role in the knitwear design situations is that of knitting machine operators (knitters). These are also usually male. They have limited training in the technical aspects of knitting machines and no training in design. Knitters typically look after several knitting machines at a time. Resolving the tensions and miscommunications between the knitwear designers on one side and knitting machine technicians and operators on the other requires significant input from both sides. Often there is confusion in understanding the reasons for the others' actions. The language and concepts of both knitwear designers creating a design and the knitting machine technicians and operators responsible for the production of a design are misunderstood by each other.

In effect, knitwear designers are hindered in creating high-fashion designs by the problems of managing the computerized seamless V-bed software in directly controlling the knitting machine. Taken together, the above factors form the crux of the problem for knitwear designers in realizing high-fashion design product using knitting machine technology.

The above factors result in a 'bottleneck' in high-fashion garment design using computerized seamless V-bed knitting systems that is primarily caused by the current workflow processes and the currently defined roles of the computerized seamless V-bed knitting machine technicians and knitters in terms of the rapid production of *1st sample*s of new high-fashion garments and the development of their knit data and program codes for sample knitwear production. In contrast, computerized seamless V-bed knitting machines are easy to obtain and knitwear designers are available to produce designs quickly, but increasing the number of machines or the number of designers will not resolve the problem. It requires changes that result in the design process to *1st sample* being appropriately resourced, and directly managed by the knitwear designer. In essence, addressing this issue is the commercial 'pain' this research cures.

Regardless of these design process problems of using computerized seamless V-bed knitting technology for high-fashion design, there are significant potential benefits for both mass retail and high-fashion garment production of using computerized seamless V-bed knitwear systems (Choi & Powell, 2005). The computerized seamless V-bed knitwear technology eliminates several garment make-up processes and enhances the potential of on-demand and simplified garment production processes for high-fashion knitwear design as much as mass retail design. In addition, seamless knitting technology changes the garment supply paradigm in time and cost and offers potential for the knitwear industry to transform from being labor-focused to being more technology-oriented.

If the problems identified in this research are addressed, the application of easy-to-use CAD systems for computerized seamless V-bed knitwear design presents the potential to seed radical innovations worldwide in high-fashion knitwear development processes across the knitwear industry perhaps offering even greater benefits that the technology has offered in the realm of routine mass-market knitwear. For high-fashion designers, especially, it offers the potential of rapid sample garment and prototype production and the creation of short runs of garments. Later, this is also identified with the idea of a new profession, the 'designer-interpreter' and a new form of 'post-industrial knitwear design craft ' in which the knitwear design artist acts as a one-person design and production factory using a computerized seamless V-bed knitting systems.

This PhD involved researching, identifying developing and testing improved, alternative high-fashion knitwear design processes, design methods and ways of teaching them. The nature of the problem obviously implied changes to the roles, workflows, processes, and, potentially, education of the three main participants: the knitwear designer, the knitting machine technician, and the knitting machine operator.

This research scope, in design process terms, was bounded on one side by yarn design and on the other by knitting machine code optimization. In theory, the design and production of a garment using computerized seamless V-bed knitwear systems includes all aspects of fashion design from yarn to production plus the code optimization for maximizing output of the seamless V-bed knitting machinery. The design areas include: fiber/yarn design, fabric design, garment design, and the necessary programming to develop code and garment samples for Shima Seiki's mass production process. This PhD did not address yarn design issues or machine coding optimization for production. The research focused solely on the processes involving fabric design, garment design, and garment sample production to the point of creating the code for, and manufacturing, a successful *1st sample* garment. Fiber/yarn design processes and mass production knitting machine coding optimizations are excluded from this PhD research.

Research questions

Following an in-depth literature review, three research questions were identified as being central to this research.

- How much of the roles of the knitting machine technician and knitting machine operator can be undertaken by the knitwear designer to the point of *1st sample* garment?
- What would be a more efficacious high-fashion knitwear design development process to the point of *1st sample* with the knitwear designer undertaking more of the roles of the knitting machine technician and knitting machine operator?

- Can this new approach be taught?

The research questions originated in a broader practical research query grounded in the reality of the researcher undertaking several real world knitting projects within the context of the PhD.

Initially, when the research commenced, the first problem for the researcher was simply how to use the computerized seamless V-bed knitting technology, in this case the Shima Seiki WholeGarment® knitting system, in any way to produce high-fashion creative wool textiles for use by five international fashion designers. This was under the tight deadline of creation of 'Design for Comfort' fashion display at the 2006 International Merino Innovation Conference.

From this traumatic start to the research, the investigation developed under the four broad themes of identifying ways of utilizing the creative potential of the computerized seamless V-bed knitwear technology. One theme was devising ways to increase the available envelope of creative possibilities. The second theme was to find ways to use the computerized seamless V-bed knitwear system without continuous ongoing involvement with and dependence on knitting machine technician support. The third theme was to identify a different workflow in which the design issues were predominately managed by the knitwear designer. The fourth theme was to develop and test ways of teaching this knitwear designer-centered use of the computerized seamless V-bed knitting system. The investigations were undertaken through analysis of the processes and outcomes of undertaking eight (8) semi-commercial high-fashion knitwear design projects involving the design and production of five-hundred thirty-one (531) knitted designs including three-hundred nineteen (319) WholeGarment® pieces, and the development and teaching of two courses and three seminars for fashion design students and professionals on using the approaches developed in this research. In addition, the researcher published two refereed papers on the research.

The first two research questions distilled the essence of the first three themes, with the third research question representing the fourth theme.

Addressing the three research questions in this PhD used a combination of research approaches that were primarily possible due to the researcher's prior skills and experiences as a high-fashion knitwear, textile designer, and manager of a computerized knitting business. As part of achieving the research outcomes, the researcher also during the research spent three periods of residential training at Shima Seiki's training facilities in Japan.

The emergence of the research questions was strongly dependent on the research practicalities in terms of dependence on access to a Shima Seiki WholeGarment® knitting system, access to Shima Seiki formal training programs, and opportunities to undertake real world high-fashion knitwear projects. These factors also influenced how the research was undertaken and how ideas for solutions were developed as these were also tightly interlinked with the same research practicalities. The timeline of development of the research question followed the approximate sequence shown in Figure 1.

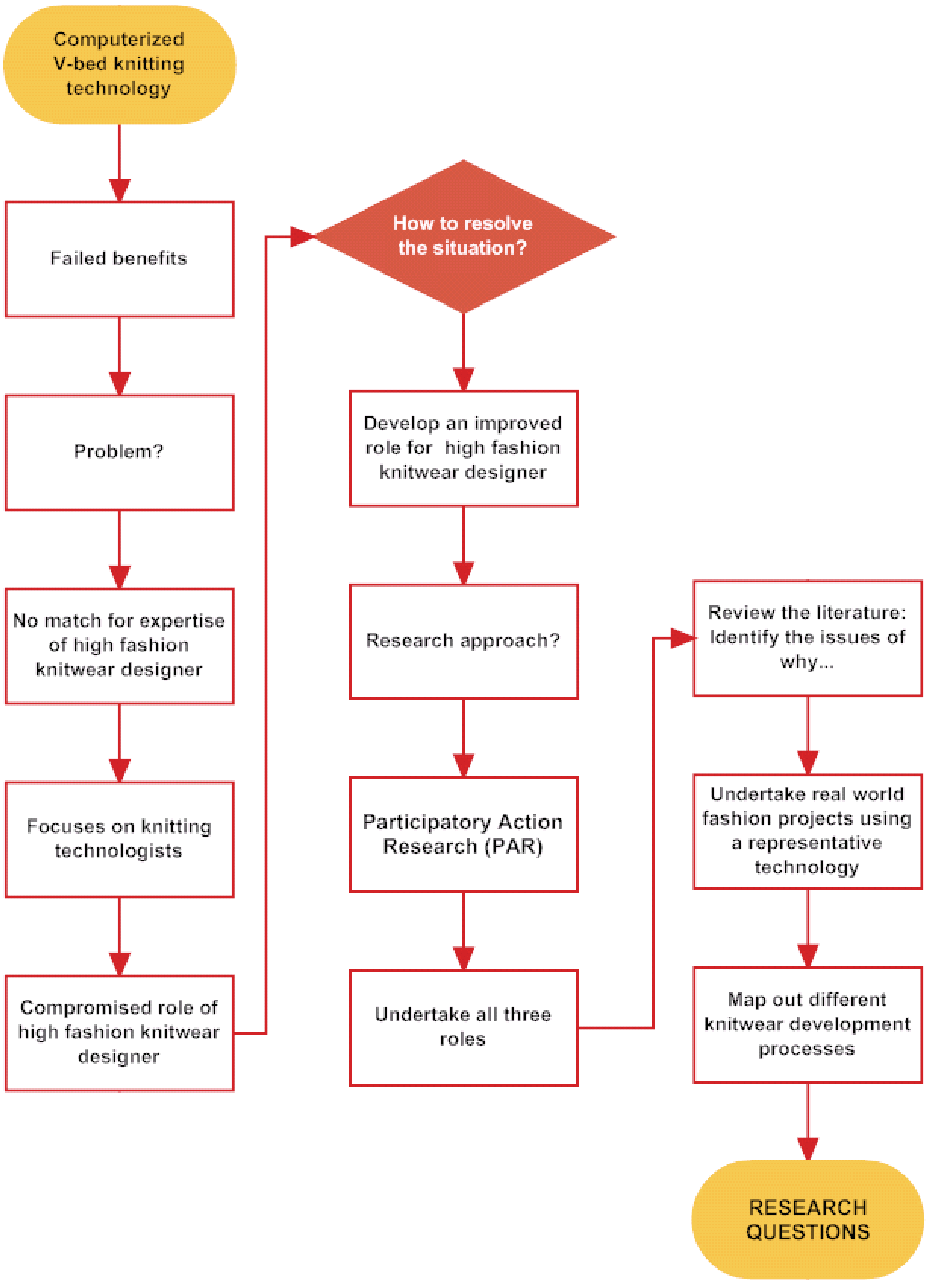


Figure 1: Evolution of the research questions

Significance of the research

This research is significant because it has resolved a major limitation for the international high-fashion industry gaining competitive advantage in the creation of high quality innovative high-fashion knitwear through the benefits available from the use of computerized seamless V-bed knitwear design and manufacturing technology. This seamless V-bed knitwear technology potentially opens up a wide range of creative opportunities for high-fashion knitwear designers along with significant changes in production, reductions in time to market, significantly reduced costs for low production runs down to individually unique garments. This enabling of increased creativity and significantly reduced production costs and time to market in high-fashion knitwear design is important for all countries and businesses involved in the high-fashion knitwear industry and it has potential trickle-down benefits for the retail mass-market knitwear trade. These benefits are potentially especially important for Australia because Australia is a major international wool provider and gains its own competitive advantage in commerce and GDP from providing quality wool for use in the high-fashion sector (DAFWA, 2006b).

Knitwear is an important component of the fashion apparel industry across all sectors, from everyday wear to the most expensive high-fashion (Jee, 2000; Jung, 2004; Lee, 2003; Nam, 2004). It is particularly significant for the many countries that have agricultural systems producing wool and other long flexible fibers that can be knitted. Each year the world produces over 17 million tons of knitted textiles and apparel − representing one third of the global textile market and outputs are forecast to grow by 25% over the next ten years, reaching more than 21 million tons (The Korea Federation of Textile Industries (KOFOTI), 2008). These textiles are the basis for the creation of ‘fashion’ and for manufacturing clothing that provide an important contribution to the GDP of many countries such as Italy, Bangladesh, South Korea, and Taiwan (Jung, 2004; Kawamura, 2004; Lee & Kim, 2003; Lee, 2003; Nam, 2004; Park & Anderson, 1991; Textile Intelligence, 2003; The Korea Federation of Textile Industries (KOFOTI), 2008).

Australian wool growers consistently produce approximately 25 percent of the global supply of raw and greasy wool; the vast majority of which is exported and used in the manufacture of quality apparel (Australian Venture Consultants Pty Ltd., 2005). Government agricultural organizations such as the Department of Agriculture and Food Western Australia (DAFWA) along with farmers are developing ultra high quality wool products (DAFWA, 2006a; Farren & Clarke, 2009; Farren, Kope, & Stanton, 2006). This PhD research was supported by DAFWA as part of developing new commercial wool industry streams and marketing ‘touch points’ demonstrate the quality and value of Australian specialist wools to the international high-fashion knitwear industry. To do this requires establishing a niche of ‘Australian specialist wool’ as a design attribute by demonstrating its benefits via high-fashion garments designed and created using cutting edge computerized seamless V-bed knitting technology. This approach is supported by the research findings of Na, Holland, Shackleton, Hwang, and Melewar (2008) that indicate the attributes of high-fashion design can have an effective promotional brand effect, such as buy ‘Australian specialist wool’. Potentially, the strength of this branding effect can override the buying influences of competitors’ and competitor countries’ brand characteristics, including the brand names of their fashion houses.

To summarize, in addition to addressing and resolving a significant applied research theoretical problem relating to designing processes and professional design practices by developing an improved high-fashion knitwear design process, this PhD research offers the basis to internationally improve the commercial aspects of high-fashion knitwear industry and Australian wool marketing outcomes. The research outcomes provide support for enhancing Australia’s competitive position in wool sales via facilitating the use of quality Australian wool in high-fashion knitwear design and production.

Technical background to research problem

The production of beautiful clothing through knitting has a long history as a hand craft (Black, 2002; Dale & Stupakoff, 1986; Harris, 1993; Newton, 1992; Stanfield & Griffiths, 2000) and more lately with semi-automated support of knitting machines used to either create knitted fabric from which garment pieces are cut and sewn together in a similar manner to woven fabric garments, or in which garment pieces are knitted to size as in hand knitting and then sewn together. Manually produced knitwear is slow and expensive to produce. Semi-automated mechanical knitting systems have been developed to reduce the cost of knitwear manufacture. There are presently five different ways to produce machine knitted garments. These include:

- *Fully-cut*: the garment parts are cut out from rolls of knitted fabric and sewn together;
- *Garment length knitting*: the garment parts are cut out from pieces of knitted fabric the same length as the garment;
- *Fully-fashioned*: each piece of the garment is knitted exactly to shape ready for sewing together;
- *Integral garment knitting*: garment details are knitted in the main pieces of the garment with little or no seam; and
- *Computerized seamless V-bed knitwear production*: a complete garment is knitted in a single piece. Typically, the design of the garment is done using the same computer system as creates the data for the knitting machine.

Computerized seamless V-bed knitting is a major breakthrough in knitted garment production. It involves using computerized automated knitting machines together with high specification desktop computers to design, and then knit complex garments in a single piece without manual stitching together of multiple pieces. This 'all-in-one' design and manufacturing knitting system targets the knitting industry and other related apparel industries and sells based on reducing costs and increasing speed to market. These systems, however, primarily focus on everyday retail apparel, for instance, cardigans, sweaters, and sleeveless tops. Computerized seamless V-bed knitwear design and manufacture is a comparatively young technology with sales of seamless units are currently around 5% of the knitting machinery market, and steadily expanding (Wilson, 2008).

Computerized seamless V-bed knitwear systems comprise separate but linked 'design' and knitwear production systems. A highly specified desktop computer console is used to 'design' garments. The knitting machine is a separate unit that operates autonomously from the desktop console. The software from the desktop console creates the knit data to operate the knitting machine. This knit data is transferred from the desktop console to the knitting machine via a USB memory stick or MO disk. The main components of a Shima Seiki computerized seamless V-bed knitting desktop apparel design system comprise a sub-keyboard (special multi-button roller-ball pointing device), LCD monitor, keyboard, digitizing tablet with stylus pen, and system unit as shown in Figure 2.

Figure 2: SDS-ONE® Apparel Design Workstation. Source: (Shima Seiki Mfg., 2007a)

Shima Seiki in Japan and Stoll in Germany are the two leading manufacturers of computerized seamless V-bed knitting technology. This research was undertaken using a Shima Seiki WholeGarment® knitting system composed of the Shima Seiki SDS-ONE® apparel design workstation and a Shima Seiki NewSES-183S•WG computerized V-bed flat knitting machine with WholeGarment® capability. 'WholeGarment®' is Shima Seiki's term for their proprietary seamless V-bed knitting technology.

The SDS-ONE® apparel design system includes an extensive collection of software to design garments and produce the knit data code to operate the knitting machine. It also includes additional software specific to spinners, designers, knitters, contract knitters, textile designers, embroiderers, and printing artists. Data created on SDS-ONE® is sent to various Shima Seiki machinery such as textile fabric printers and fabric cutting machines for production (Shima Seiki Mfg., 2008a).

The knitting machine, NewSES-183S•WG, has 72 inch-long (183 centimeters, 1,008 knitting needles) knitting width with a machine controller console that is used to adjust sundry knitting machine parameters that act with the knit data in the knitting process (Figure 3). Faulty knitwear outcomes result from problematic combinations of knit data and knitting machine parameter settings.

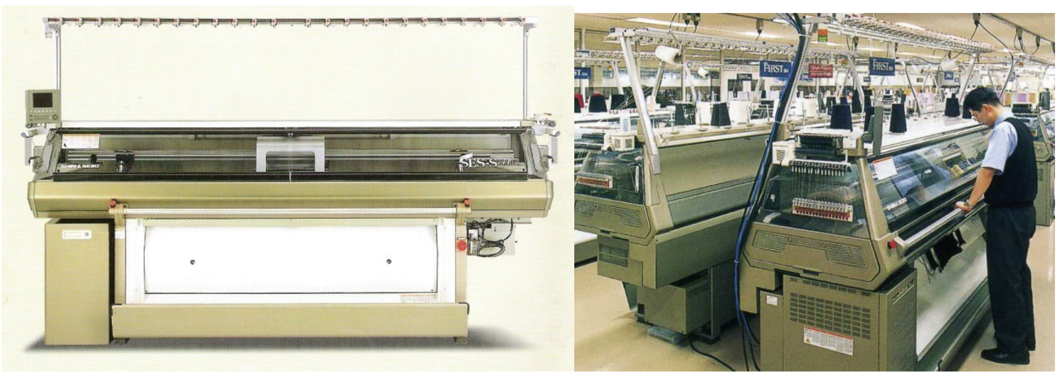


Figure 3: NewSES-183S•WG: Entry-level WholeGarment® production model. Source: (Shima Seiki Mfg., 2008e)

The desktop apparel design workstation and the knitting machine function together but are substantially separate in operability, which enables the possibility for a single apparel workstation to be used with multiple knitting machines.

When considering the benefits of computerized seamless V-bed knitting technology, it is helpful to view the 'design' and 'production' aspects of the computerized seamless V-bed technology separately. This was particularly important in this PhD research because of its focus on the 'design' aspects of computerized seamless V-bed knitwear and the different roles and processes of the professionals involved in the design of a garment. The benefits and limitations of computerized seamless V-bed knitting are different for design and production.

The design functionality of the Shima Seiki WholeGarment® knitting system is provided mainly by two software applications: *Design* and *KnitPaint*. The *Design* software is aimed at enabling designers to create portfolios of visual images of designs to be perused by buyers. The output of *Design* is primarily visual images with garment information that describes to buyers each different garment that the designer conceives to make available for sale. The choice of designs in the *Design* software is limited by a fixed gallery of garment patterns to which the designer can add visual details. In addition, the *Design* software supports the conversion of color images into knitted patterns and motifs that can be added to a basic garment shape. At its simplest, this enables a color photograph of (say) the face of a celebrity to be knitted in color on the front of a sweater. The current approach of computerized seamless V-bed knitting technology is to attempt to automate the fashion design aspect of knitwear production by reducing fashion knitwear design to select simple standardized knitted garments with a small range of garment styles and decorations to be chosen by a knitting machine technician rather than a knitwear designer.

For high-fashion designers, a significant limitation of the *Design* software is that it is tightly linked to, and dependent on, standard pre-registered garment shapes in the garment shape gallery. These pre-registered garment shapes are of typical simple garments common to retail mass-market knitwear. These pre-registered shapes are very different from what is needed to extend the design envelope of the computerized seamless V-bed knitting system to the point where it can offer creative potential for high-fashion design.

Separate from, and more complex than the *Design* software, is the *KnitPaint* software. This software application is the real driver of the knitting machine. The *KnitPaint* software creates the knit data used by the knitting machine. The *KnitPaint* software has two primary roles. The first is the simplest. It converts into knit data from *Design* its mass retail designs in a simple, easy to use straightforward non-technical way. The second role of *KnitPaint,* its real role, is as a direct technical programming tool for knitting machine technicians to program the computerized seamless V-bed knitting machine directly (Eckert, 2001; Shima Seiki Mfg., 2008g). The way *KnitPaint* has been design for this latter role makes its functionality highly inaccessible for use by high-fashion designers. A substantial part of this research focuses on addressing this problem.

Unless the high-fashion knitwear designer can interact at the level of control of the knitting machine enabled by the *KnitPaint* knitting machine software, she/he is totally dependent on knitting machine technicians to undertake technical programming to generate the knit data necessary to knit samples of garments. This generation of knit data has to date been highly technical and the sole province of machine technicians, and requires long technical training undertaken only at the manufacturers' place of business. Very few knitwear designers attend this long-term overseas residential training on computerized seamless V-bed software programming.

This leads to a restating of the research problem in technical terms, resolving the research problem and enabling the use of computerized seamless V-bed knitting for high-fashion designers requires radically reducing the dependence of high-fashion knitwear designers on knitting machine technicians and knitting machine operators in creating the designs up to the point of *1st sample*. It requires changes in the computerized seamless V-bed knitwear design workflows and processes, the identification of more accessible ways that high-fashion designers can more directly use the *KnitPaint* application to open up the functional envelope of the computerized seamless V-bed knitting system to that needed for high-fashion garments at least to the point of *1st sample* making, changes to the roles of the three main professionals to date involved in the design process, and changes to the education of knitwear designers to enable them to fulfilll their new role in this new workflow.

Theoretical and methodological perspectives

This research uses *participatory action research* (PAR) as its primary theoretical perspective (for a description of PAR, see, for example, Wadsworth, 1988). As part of this research, the researcher undertook several semi-commercial knitwear projects using a computerized seamless V-bed knitwear design and manufacturing system. These provided the opportunity for the researcher, following a classic action research (AR) paradigm, to design garments, assess the problems and benefits of the workflow process she used, reflect on the process and benefits and lessons, and modify the process. The details of the research methodology are described more fully in Chapter 6.

In parallel, the computerized seamless V-bed knitwear design and manufacturing process and its integration with the different aspects of the international fashion and retail industries was regarded by the researcher as a socio-technical system (see, for example, (Ropohl, 1999; Trist & Ontario Quality of Working Life, 1981)). Viewing the research problem and context in terms of 'socio-technical systems', enabled the inclusion of both the technical and human issues of the knitwear design workflow to be researched and analyzed simultaneously using the same methodology and research approaches. In turn this enabled new workflow processes to be developed and trailed within the participatory action research paradigm of the research.

Using this theoretical perspective of participatory action research, the researcher's applied data collection and analysis were divided into four applied research pathways:

- Use, test, and redesign a variety of approaches across several projects and hundreds of knitwear outputs to use the *KnitPaint* and other software to open up the functional envelope of the computerized seamless V-bed technology to give more creative opportunities to fashion designers for high-fashion design;

- Mapping the design and manufacturing workflow processes for the different roles of fashion designer, knitting machine technician and knitting machine operator, and developing improved processes that facilitate the use of the computerized seamless V-bed knitwear technology by high-fashion designers. This resulted in a new integrated computerized seamless V-bed knitwear design and manufacturing process up to and including *1st sample*;
- Self-review of the researcher's own experiences in training at Shima Seiki in Japan and working in knitwear design and manufacturing in the East Asia, Europe, and the US; and
- Developing and trailing educational courses using the new design process for university fashion design students and knitwear design professionals.

The problem addressed by this research required the researcher to undertake more roles than is usual in participatory action research. This research project is complex: it involves technical processes, information processes, human processes, and content and professional skills in multiple professional domains including high-fashion knitwear, business management, craft, and art. As a result, this research required a more complex approach than the simpler and more common structures of Participatory Action Research. In Participatory Action Research, the most common scenario is where the researcher acts in a *single* role as a participant in the situation being researched. For example, in education research, the researcher might participate as a teacher. The participatory action research undertaken for this PhD is unusual in that the researcher participated separately and sometimes simultaneously in the following roles:

- High-fashion knitwear designer;
- Knitting machine technician;
- Knitting machine operator;
- New integrated high-fashion knitwear designer, programmer, knitting machine operator (defined by the researcher is 'designer-interpreter'); and
- Fashion design lecturer.

At different points in the research, the research discussions and analyses necessarily refer to others who were involved in the practical and educational activities of the real world projects in a variety of ways. Regardless of the reality that these projects were in the public domain and the commercial intellectual property issues were managed external to the research, identifying individuals potentially presents minor ethical issues on fronts that cannot be simply determined due to the complexity of the social and institutional relationships. To avoid individuals being readily identifiable in the discussions and analyses, *work titles* rather than names have been used to refer to the individuals involved in the research activities in order to obscure their identities in the manner suggested by Grinyer (2002).

Practical knitwear design and manufacture projects

This applied participatory action research was centered around and grounded on undertaking a total of eleven (11) semi-commercial knitwear design projects and seminars using the Shima Seiki WholeGarment® machine to explore how best to integrate within the role of the knitwear designer the conventional high-fashion 'knitwear development process' with knitwear design using the software that knitting machine technician's use (*KnitPaint* in the case of Shima Seiki WholeGarment® system) along with 'knit data programming' and 'operating' the computerized seamless V-bed knitting machine. The projects included:

- Tube sessions with Curtin University of Technology students involved applying computerized seamless V-bed knitting technology to their design practices (2008);
- Designing and creating outfits for dancers at the Dance Performance Night at the Live Stock Updates Conference (2008);
- Professional Practicum 390 unit project (2008) that involved providing Fashion and Textile Design students at Curtin University of Technology with a practical and short-term internship experience in computerized seamless V-bed knitting technology;
- Working with an Italian designer Bianca Gervasio (2007). This project involved creating knitted fabrics and computerized seamless V-bed knitwear using Shima Seiki WholeGarment® knitting system featured on AltaRomAltaModa fashion week (AltaRoma, 2008);
- Tube sessions with Curtin students that explored computerized seamless V-bed knitting technology (2007);
- Seminar for TAFE students (2007) that involved knitwear production using computerized seamless V-bed knitting technology;
- Cone-shaped artifact project (2007) that explored programming and knitting an unusual gigantic lamp shade for display at Burswood Casino;
- 'Wagin Woolorama Ambassador' (2007) that involved creating two sets of computerized seamless V-bed knitted outfits for the (female) ambassador;
- 'Design for Comfort' (2006) that involved creating complex knitted wool fabrics for five Western Australian fashion designers (DAFWA, 2006a);
- Seminar for TAFE students (2006) that involved garment production using the latest knitting technology; and
- Belmont DesignEdge Festival workshop (2006) involved demonstration of computerized seamless V-bed knitting technology.

During the research, a variety of ideas were developed that together comprised an evolution of approaches to undertaking computerized seamless V-bed knitwear design by the knitwear designer alone. This was supported by process mapping of the workflows of existing computerized seamless V-bed professional roles and led to the development of a new integrated computerized seamless V-bed knitwear design process that depended only on a knitwear designer with some additional training in the technical aspects of computerized seamless V-bed knitwear design. The potential for teaching this new integrated design and manufacturing process to Fashion and Textile Design students and practicing designers was practically and successfully trialed through courses and seminars.

This led to an additional outcome: the development and testing of new short fashion design courses that included computerized seamless V-bed high-fashion knitwear design and manufacture and an understanding on how using this technology can improve fashion design education.

Outline of research findings

This PhD research resulted in findings that appear to fully resolve the research problem of making the computerized seamless V-bed knitting technology more accessible for high-fashion knitwear designers. The practical outcome of the research was a coordinated suite of strategies involving the development of a new high-fashion knitwear design and manufacturing workflow process for computerized seamless V-bed knitting, a definition of new roles in this workflow, development of new design methods, extension of the functional envelope of performance of the computerized seamless V-bed knitwear system to include more creative opportunities for the design of high-fashion knitwear and the development of new fashion design courses to help fashion designers adapt to this new technology. The new high-fashion knitwear design process developed in this research involves the knitwear designer undertaking *all* roles and tasks in using the computerized seamless V-bed knitting system up to and including to the creation of the completed *1st sample* and its handover to the knitting machine technician for mass-production knitting code optimization. It resolves for high-fashion designers the problems and inefficiencies of the manufacturer's design process for computerized seamless V-bed technology, and also resolves the substantial conflicts of role and tasks between knitwear designers, knitting machine technicians and knitting machine operators.

Taken together, the researcher identified and tested a new process for high-fashion knitwear design using computerized seamless V-bed knitting technology that addressed the foundational problem issues and provided the framework for the development of the other supporting strategies.

Historic precursors of this research

There are three precursors to this research that indicated the likely problems and development trends in the fashion industry of the use of the computerized seamless V-bed knitwear technology. These were identified by the researcher some years before undertaking this PhD:

- The 80s Japanese notion of transforming apparel industry production into an office-like environment;
- Morphologically-based solutions to silhouette change problems during the garment development process; and
- Insights into new garment forms from studying topological transformation of existing traditional garment patterns.

In 1989, the researcher encountered the Japanese notion of office-like apparel industry environment at an apparel automation machinery exhibition in Japan. The production employees wore office-girl uniforms and were working on fully automated apparel machinery in an office environment. This approach to knitwear design and production contrasted with even the most prestigious high-fashion knitwear companies where work environment was similar to the smallest and poorest knitwear factories with untidy garment assembly room, and knitting machinery room where talk was impossible due to machine noise. At that time, working on computerized knitting machines was regarded as a promotion as it involved working in fully air-conditioned relatively quiet and clean environments required for the machines.

Later, in 1994, the researcher saw similar office-like apparel industry workspaces on a trip with the Korea Textile Federation to Shima Seiki in Japan. These office-like environments help open up the possibility to integrate the high-fashion garment design process with the direct use by designers of the computerized seamless V-bed knitwear technology. In conventional high-fashion knitwear, a significant amount of effort is spent ensuring manufactured garments are identical to the design specifications of *1st samples* as conceived and approved by the fashion designer. The researcher had many years ago conceived of this in terms of a one-person fashion designer garment production factory. The approach described in this research provides the practical basis for such an endeavor.

Some years ago, the researcher worked on a garment patternmaking idea that involved topologically transforming simple geometric shapes, as seen in many traditional Asian garments, into other garment shapes. The intention was to find garment shapes that could be knitted, are contemporary, and support or emphasize the beauty of the fabric; which is often compromised when made into a garment. The Hanbok-Pagi, one of Korean traditional male garments was used as the basis for exploring solutions:

- Its construction is not restricted to fabric width;
- Its unusual geometric shapes align with simple hand frame knitting; and
- Individual pattern pieces can be radically transformed in size and shape whilst still maintaining the garment topology leading to new garment possibilities.

Hanbok-Pagi represents the principles of the universe; the rounded waistband for the sky, rectangular pattern pieces for the ground, and triangular pattern pieces for the human being (Lee, 1999)(Figure 4).

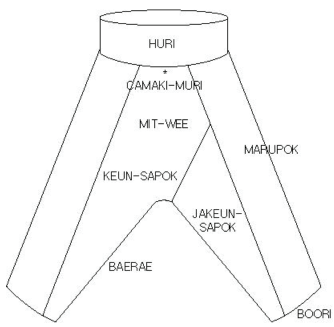


Figure 4: The shape and names of Hanbok-Pagi pattern pieces

Several new knitted garment shapes resulted from transforming pattern pieces along with some interesting combinatorial possibilities that in this PhD emerged as the basis for the slash and slit garments described in later chapters and the appendices and shown below in Figure 5.

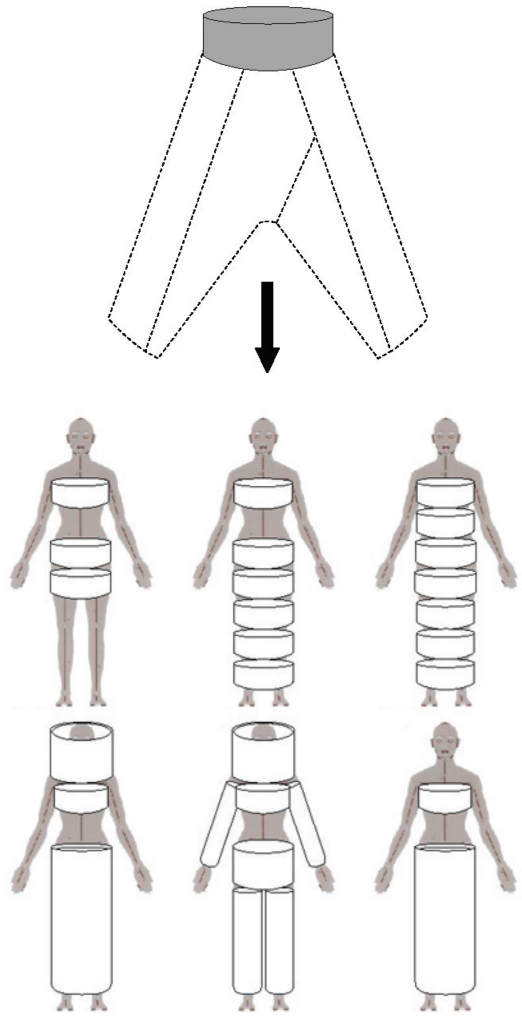


Figure 5: Design development based on Hanbok-Paji waistband

Those newly developed shapes can be translated into many different garment versions or transformed into other shapes. Knitted and woven fabrics, as contemporary garments, can achieve these shapes. Furthermore, the manipulation of this and other traditional geometric garment patterns offers numerous possibilities of new forms of contemporary high-fashion garment designs through mid-gauge computerized seamless V-bed machine knitting.

CHAPTER 2: Knitted Textile Structures, Stitches, and Garments

This chapter draws on the textile literature and current fashion knitwear to provide an overview of textile concepts including the classification of types of woven and knitted structures, the structure of individual stitches, and garment construction issues essential to framing the textile side of this research and providing a theory foundation relation to textile structure issues.

Knitting as a textile

The term ‘textile’ refers to any material which has been woven, knitted, bonded, felted, fused, or otherwise manufactured (McIntyre & Daniels, 1975, p. 193). Textiles are used for a wide variety of purposes, in fields as diverse as industry, sport, and building construction (Stecker, 1996, p. 203). According to Hatch (1993), there are five forms of textile fabric structures: knitted fabrics, woven fabrics, twisted and knotted fabrics, non-woven fabrics, and compound fabrics. Hatch (1993, p. 312) also described fabrics as:

> *… manufactured assemblages of fibers and/or yarns that have substantial surface area in relation to thickness and sufficient mechanical strength to give this assembly inherent cohesion. The nature of yarn or fiber arrangements determines the type of fabric structure.*

Spencer (Spencer & Knovel (Firm), 2001, p. 1) has a similar description:

> *Textile fabrics can be produced directly from the webs of fibers by bonding, fusing or interlocking, but their physical properties tend to restrict their potential end use.*

Spencer continues that the mechanical manipulation of yarn into fabric by interweaving, intertwining (also twisting), and inter-looping is the most versatile method of manufacturing textile fabrics for a wide range of end-uses.

Knitted fabric structures

Figure 6 illustrates the structural differences of fabric structures. Knitted fabrics are formed through the process of interlocking loops or forming loops with one or more yarns in preceding and succeeding rows (Gioello, 1982, p. 57). Woven fabrics have two or more sets of yarn that are interlaced at right angles to each other (Long, 2000, p. 4). Weaving is the oldest and most common method of producing continuous lengths of straight-edged fabric (Spencer & Knovel (Firm), 2001, p.1). Twisted and knotted fabrics have yarns that intertwine with each other at right or other angles (Hatch, 1993, p. 312). The techniques to create these fabrics include braiding and knotting: these techniques tend to produce special constructions whose uses are limited to very specific purposes (Spencer & Knovel (Firm), 2001, p. 2). Knitting, for example, has been used by sailors, especially in elaborate or ornamental forms to decorate anything from knife handles to bottles to parts of ships (Harris, 1993, p. 95). Macramé is a form of textile making exclusively through the use of knotting, which became popular in the twentieth century (Harris, 1993, p. 49). It is viewed as a more feminine form of craft compared to traditional knitting techniques (Answers Corporation, 2008; Harris, 1993). Non-woven fabrics are usually made from extruded continuous filaments or from webs or batts that are entangled or layered. The fibers are often bonded with adhesives, thread stitching, or other means (Hatch, 1993, p. 361). Compound fabrics are composed of two or more layers of fabric and another component (yarn, fiber, vinyl, film, etc.) held together by stitching, fusing, adhesive, or bonding (Hatch, 1993, p. 371).

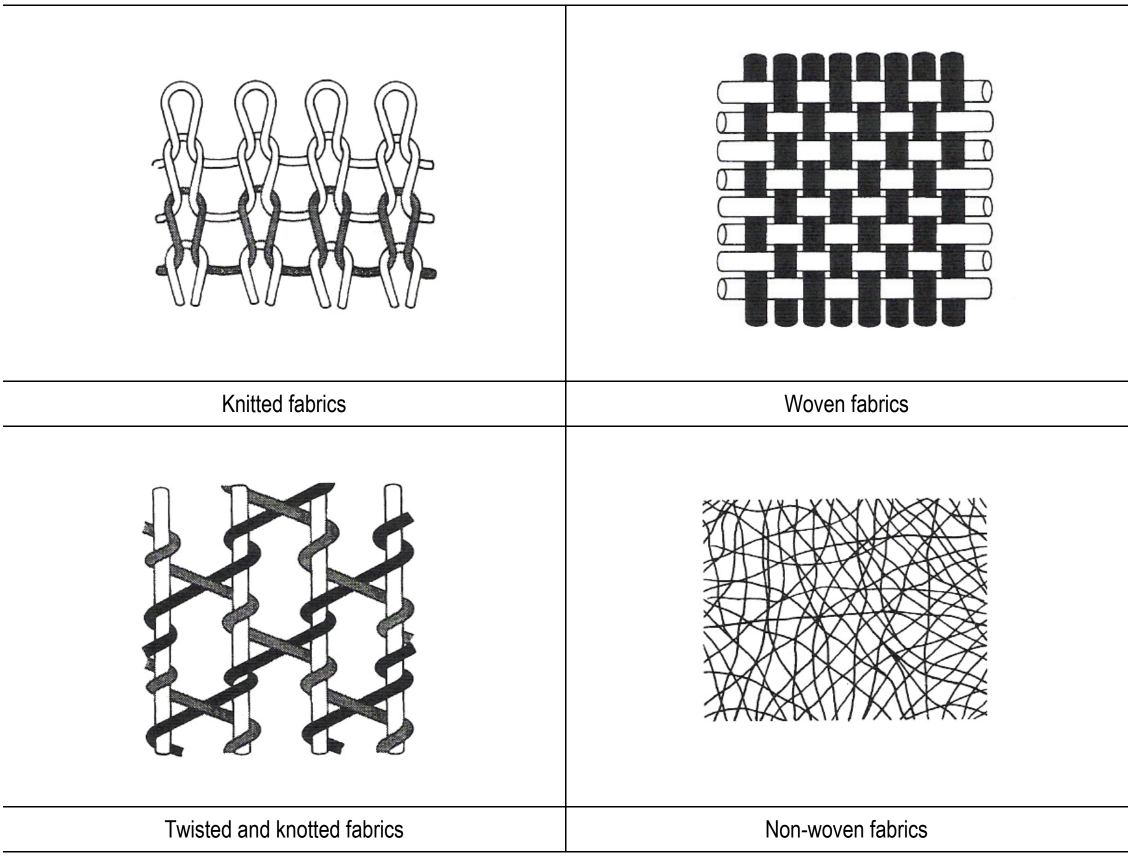


Figure 6: Fabric structures. Source: (Hatch, 1993)

Types of knitting

In this section, the focus is on weft knitting and the alternative, warp knitting, will be described in a later section.

Knitting is considered to be the second most common method of constructing fabric after weaving (Long, 2000, p. 4; Spencer & Knovel (Firm), 2001, p. 2). It is the process of making a fabric or an item of apparel, by the interlacing of loops either by hand or by machine (Calasibetta, 1988, pp. 316-317). The loops may be either loosely or closely constructed, according to the size of knitting needles and/or size of yarn (Gioello, 1982, p. 57). Knitting is different from weaving because a single thread of yarn can be used to create fabric. The knitted fabric consists of horizontal rows of loops known as 'courses' and vertical columns of loops known as 'wales' (Spencer & Knovel (Firm), 2001, pp. 16-17) (Figure 7).

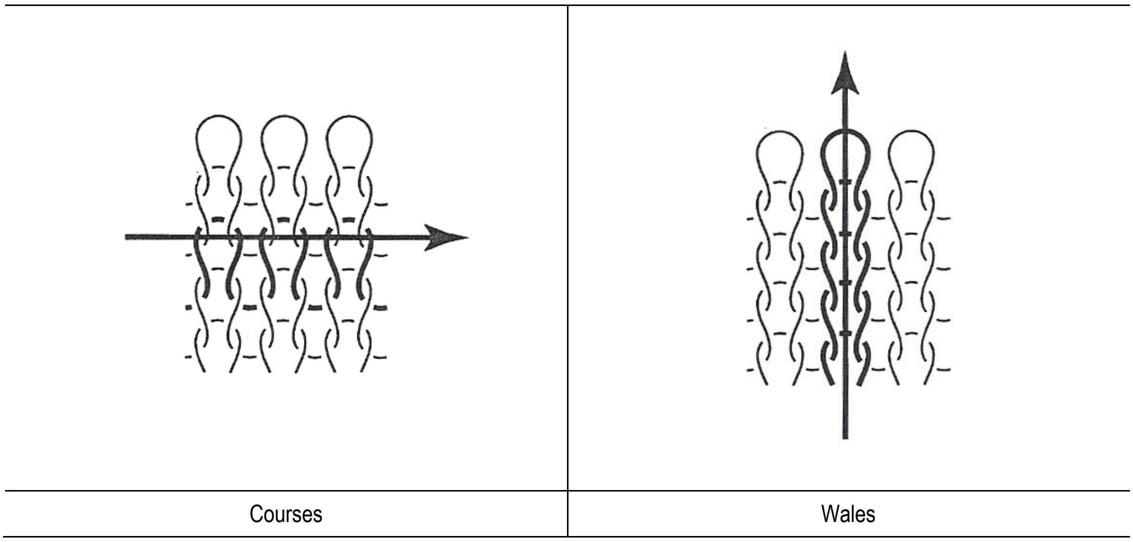


Figure 7: Courses and wales. Source: (Fashion Business Society, Committee for Textile Terminology Research, & Committee for Knitting-Related Terminology, 2000)

Knitting is a method of converting yarn into fabric by intermeshing loops, which are formed by hand or a knitting machine, with one or more needles of different types (Gioello, 1982, p. 57; Hatch, 1993, p. 342). There are two basic forms of knitting technology, weft and warp knitting. Long (2000, p. 6) describes the two types of knits in this way:

> *Weft is synonymous with filling in weaving and signifies crosswise looping in knitting. Weft knitting is like hand knitting in that it uses the same basic stitches: plain, purl, and rib. Rows of loops, each caught into the previous row, create the fabric. Warp is*

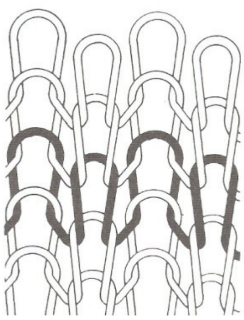
> *synonymous with lengthwise direction in weaving. Warp knitting is done on a machine and cannot be done by hand.*

Gioello (1982, p.61) explains it in a more technical sense (Figure 8):

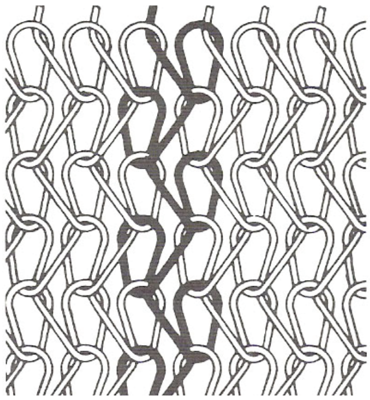
> Weft knitted fabrics are produced by adjacent needles which draw a yarn from a creel attached to *the knitting machine while warp knitted fabrics are produced by several parallel yarns that form one stitch for each yarn in each course.*

Gioello (1982, p.61) further describes that the differences in the two types of machine knitted fabric structures:

> *All the needles operate independently of one another and all the stitches in the course are made by one yarn in weft knitting. On the other hand, all the needles move up at the same time to make the stitch in warp knitting.*



Weft knitted fabric



Warp knitted fabric

Figure 8: Weft and warp knitted fabric structures. Source: (Gioello, 1982)

Weft knitting simulates hand knitting procedures (Long, 2000, p. 6). Flat knitted fabric can be made with the use of straight knitting needles and as seamless tubular pieces with circular knitting needles (Buss, 1999). There are three classes of weft knitting machines: flat, circular, and straight bar frame machines (Spencer & Knovel (Firm), 2001, p. 85). Fabrics can be produced in either flat or tubular form (Gioello, 1982, p. 61). There are also two types of flat machines: V-bed and links-links machine (Spencer & Knovel (Firm), 2001, p. 207).

Weft knitted fabric is generally highly elastic and highly drape-able. Its two attributes, porosity and elasticity, make it suitable for a wide range of apparel applications – for example, comfortable for both outer garments and undergarments (Gioello, 1982, p. 57).

It can be produced as shaped fabrics as well as integral knitted products (Hatch, 1993, p. 342).

In contrast, the work progress of warp knitting, which is done only by machine, is length-wise. Its technology yields mostly flat goods with straight edges (Gioello, 1982, p. 61). The main advantage of warp knitted fabric is that it is not easy to unravel. However, some of these fabrics are not as stretchy as weft knitted fabrics (Long, 2000, p. 6). It can be produced from narrow fabric widths to widths up to 168” (Gioello, 1982, p. 61). Warp knitted fabrics are classified into two major categories: Tricot, Rachel, and several minor categories (Pizzuto, Price, & Cohen, 1980, p. 166). Most ace and net fabrics in the market are products of warp knitting, and also elasticized fabrics, pile fabrics, and double fabrics (Hatch, 1993, p. 360).

Knit stitch topology

The topology of a knitted fabric is not a simple one. In knitted fabric, strands follow a loopy path along its row. But in case of woven fabric, strands usually run straight horizontally and vertically. Most knits stretch more in one direction than another (Richardson, 2008, p. 2). Depending on the yarn fiber and the specific stitch pattern used, some are more stretchable than others. This is because there is no single straight line of yarn anywhere in the knitted fabric. This stretchiness is not seen in woven fabric. That is why, in most of modern stretchy garments, some of their stretch is attained through knitted fabrics, even if they rely on elastic synthetic materials for stretch.

There are four fundamental stitches in weft knitting: knit (face loop), purl (back loop), float (missed loop), and tuck (held loop) stitches (Figure 9).

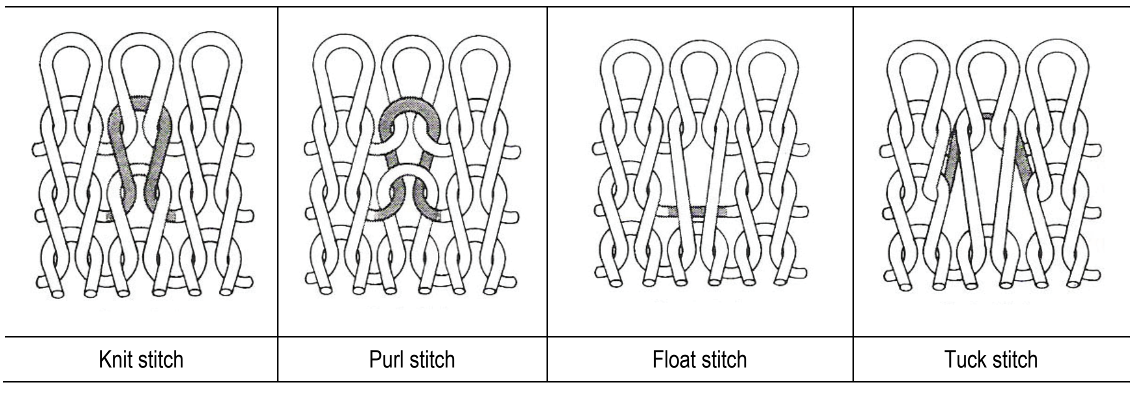


Figure 9: Fundamental stitches in weft knitting. Source: (Hatch, 1993)

All knitted fabrics have a definite right side (face) and wrong side (back). The visible portions of the loops are the verticals connecting two rows, arranged in a grid of V shapes on the right side. On the 'wrong' side, the ends of the loops, both the tops and bottoms, are visible (Figure 10).

Stitches on the knitted fabric can be worked from either side. Many stitch patterns are created by mixing knit stitches with the 'wrong side' stitches, known as purl stitches, either in rows (garter or welting), columns (ribbing) or more complex patterns. Figure 10 shows the right and wrong sides of 'jersey'. The jersey (plain, stockinet) is one of three basic single weft knitted fabrics, the others being rib and purl fabrics (Hatch, 1993, p. 348).

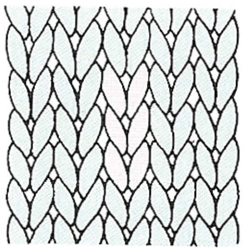
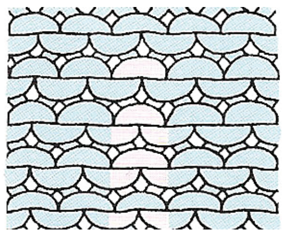
	
Right side	Wrong side

Figure 10: The right and wrong side of jersey. Source: (Japan Vogue, 1997)

Although the single weft knitted fabrics have one layer of loops formed with one yarn system, the types of stitches and their sequence in the three knitted fabrics cause various structural as well as performance variations (Gioello, 1982; Hatch, 1993; Lee, 2003; Newton, 1992; Pizzuto et al., 1980; Spencer & Knovel (Firm), 2001) (see Figure 9).

Properties and performance of knitted fabric

Knitted fabrics have different properties, depending on stitches and stitch patterns. For example, weft knitted fabrics can be:

- Gauzy to very dense;
- Highly stretchy to relatively stiff; and
- Flat to tightly curl.

A large variety of stitches and yarns may be used to give textured effects and surface interest (Calasibetta, 1988, p. 317). For example, there are knitting yarns made from animal fibers, vegetable fibers, and synthetic fibers. There are also many novelty and specialty yarns available in the market. The term 'novelty' is used to describe a yarn with an interesting surface texture while the term 'specialty' is a yarn or strand (not all from fibers) that is not specifically marketed for hand knitters (Newton, 1992, p. 21). Some specialties are functional; others are solely decorative: elastic yarn is an example of a functional specialty yarn. The appearance of a knitted fabric is also affected by the weight of the yarn. The weight describes the thickness of the spun fiber. The thinner the yarn, the finer the texture of the knitted fabric; and the thicker the yarn, the more visible and apparent the stitches will be.

The general performance of weft knitted fabrics is described best by examining the advantages and disadvantages of these fabrics (Gioello, 1982, p. 57; Hatch, 1993, p.345).

The advantages are:

- Figure-fitting yet comfortable because the fabric moves easily with body movements;
- Soft draping quality;
- Naturally inherited elasticity and resiliency;
- Wrinkle resistant (ease of care); and
- Insulation properties in still air.

On the contrary, the disadvantages are:

- High potential relaxation shrinkage;
- Poor shape retention;
- Pilling and snagging;
- Running or laddering;
- Poor insulation properties in breezy weather; and
- Advantages of knitted garments.

Knitwear versus wovenwear in garment constructions

The knitted fabric differs from the woven fabric in many ways. Because of its loopy fabric structure, the knitted fabric fits the body much more easily than the woven fabric. Thus, it is possible to simplify the garment construction without sacrificing the garment silhouette. Darts become unnecessary in most cases. Zippers, which are seen on woven tops and bottoms for close body-fitting openings, can be eliminated because of the stretchiness of the knitted fabric. Garment construction using knitted fabrics does not require as much ease as woven fabrics. Depending on the type of knitted fabric and garment style, there can be zero ease or even negative ease applied – for example, swimsuits and leotards (Long, 2000, p. 6). Moreover, the soft draping quality combined with high technology knitting often creates an unexpected serendipitous look with the simplest garment construction method.

Figure 11 displays a knitted garment composed of an all-in-one tubular shape with multiple slashes. There is no cutting line or sewing involved in making close form-fitting silhouettes. It would require much more time to create the garment if this style was to be made in a woven fabric and the result would be far from satisfactory.

Figure 11: Tube garment. Source: (DAFWA, 2007)

Recent industry experience with a garment manufacturer in Perth, WA illustrates the advantage of knitted garment over woven garment in production.

The company produces evening wear and special occasion dresses (EWSOD) from size 4 to 22; there are ten (10) incremental sizes involved – i.e., 4, 6, 8, 10, 12, 14, 16, 18, 20, 22. Knitwear usually covers from three to five size ranges at a maximum; petite, (small, medium, large), and extra large. Comparing garment construction, the EWSOD is much more complicated than knitwear. Also, there tends to be many more style lines to accentuate women's body parts or body silhouettes for the EWSOD. The style lines are created, fabric is cut into pieces, and then, the cut pieces are sewn together. More style lines mean more pieces are required to form a garment. For example, there are forty (40) pieces to construct a 3/4 length strapless halter necked cocktail dress while it can be done as a one-pieced dress on a computerized seamless V-bed knitting system. Moreover, there are at least twelve (12) markers (4 different size rage group X 3 different garment components) that are needed to produce cocktail dresses from size 6 to 22 in production quantities. Table 1 shows the number of garments to be produced in different size ranges. The table also indicates sizes in the same color are laid as one (1) marker because the sizes are in the same quantity or they are in multiple proportion:

Table 1: Number of garments required in different size ranges

Size	6	8	10	12	14	16	18	20	22
Number of garments	30	40	50	30	30	20	16	16	16

In this case, each garment layer needs three (3) sets of markers based on the model: self, lining, and shape-well. The self is a fabric that is used as the outside surface of a garment. The lining is the inside fabric of a garment. The shape-well is a piece of cloth that keeps the garment shape in place where it is necessary – for example, to keep a strapless cocktail dress on the bust. The marker needs to work on a new marker if the quantity of garment varies according to the size range. If the cocktail dress was to be produced on the WholeGarment® knitting system, five (5) different programming for the size specifications would be needed to produce the dress in five different size samples. The relation between quantity and size range would not matter. The developed programs can be reused anytime without any modification.

CHAPTER 3: History of Computerized Seamless V-bed Knitwear Technology

This chapter will review the history of knitting development from early hand knitting to computerized seamless V-bed knitting technology. The history provides an overview of the different types of non-seamless V-bed knitwear production methods. This historical analysis is followed by a discussion of the dependence of the mainstream fashion knitwear trends on computerized knitting. It includes a categorization of research literature specific to computerized seamless V-bed knitting technology. The following chapters, Chapters 4 and 5, discuss the relevant literature, concepts, theories, interventions, design processes, and background contextual issues to assist with understanding the details of the applied research problem addressed in this PhD.

The journey from hand knitting to hand operated machines to computerized machines has been a long one. The following section describes the evolution of hand knitting and machine knitting, and concludes with a discussion of the latest development in machine knitting, which is computerized seamless knitting. The main developments in knitting machines and methods are shown in Figure 12.

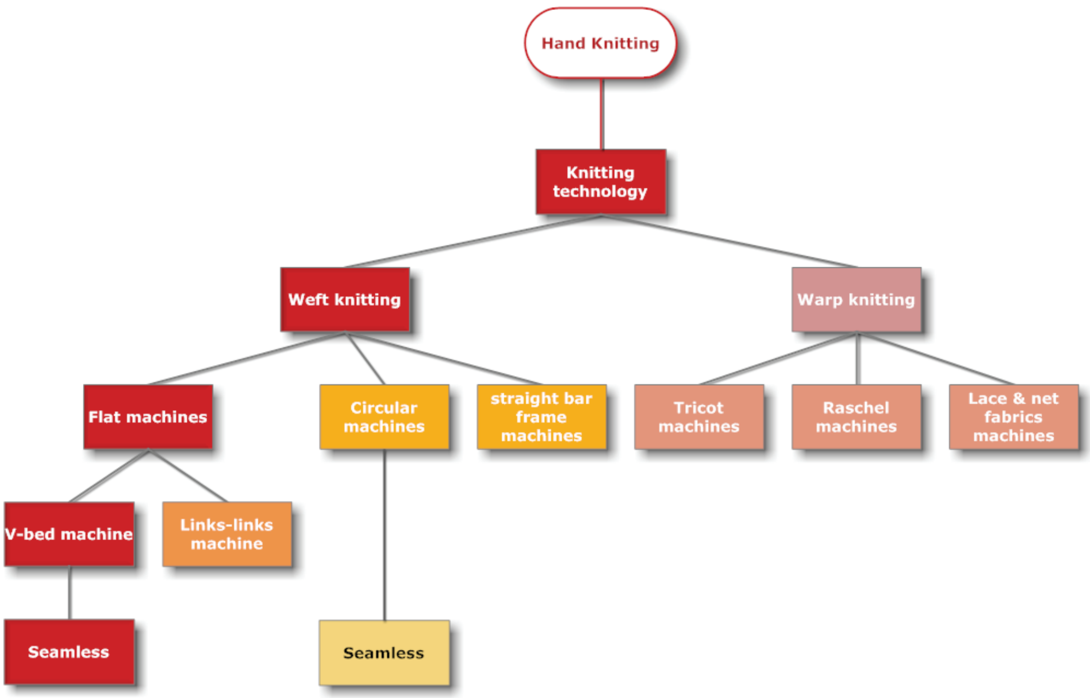


Figure 12: Classification of knitting technology

Evolution of hand knitting

Where knitting began is difficult to trace (Donofrio-Ferrezza, 2008, p. 126; Human Resources Development Service of Korea, 1996, p. 3; Lee & Kim, 2003, p. 574). Some claim Israel, Jordan or Syria as its place of origin; there are others who claim that the knitting craft originated in the mountains of North Africa. Hand knitting has been practiced for thousands of years. One needle knitting, 'Nalbinding', is the earliest known method. Nalbinding is a combination of netting and knotting, a stitch made with one needle (Donofrio-Ferrezza, 2008, p.126). The origin of two needle hand knitting is believed to have originated in Persia (Knitwear, 2008).

The earliest known knitted fabric is a pair of socks dating back to the 5th century B.C. found in an Egyptian tomb (Donofrio-Ferrezza, 2008, p. 126; Human Resources Development Service of Korea, 1996, p. 5). Knitted cushions have been found in Spain in tombs dating from the thirteenth century (Lee & Kim, 2003, p. 576). It is believed that Spain was the first European country to practice the art of knitting in a widespread manner (Donofrio-Ferrezza, 2008, p. 127).

In medieval Europe, hand knitting was an important industry (Vohra, 2008). For example, there is evidence in four surviving paintings from the 14th century that show the Virgin Mary knitting, suggesting that this craft was a familiar activity among women of the 14th century (Knitwear, 2008). The paintings document that knitting was part of everyday life at the time (Donofrio-Ferrezza, 2008, p. 127). Hand knitting spread rapidly throughout Europe within a few generations. By the 16th century, hand knitting had developed into an advanced craft (Vohra, 2008). The development of commercial knitwear as known today was previously based on the demand for men's hosiery in the 16th and 17th centuries (Donofrio-Ferrezza, 2008, p. 128). Most of that hosiery was produced by women's vigorous and accomplished skills in hand knitting.

Evolution of machine knitting

The first knitting machine was invented in 1589 by William Lee, a clergyman in England, to increase the production of hosiery. His aims, however, were not realized in his own lifetime. Queen Elizabeth I blocked its use because she considered the invention a threat to the socio-economic stability of the country's hand knitters, who were primarily agrarian women (Donofrio-Ferrezza, 2008, p. 129). Two centuries later, in 1759, the Derby Ribber was patented by Jebediah Strutt (Gartshore, 1983, p. 92). The Derby Ribber was a double-bed machine capable of knitting rib fabrics. It has been regarded as the second most important machine in the history of knitting (Donofrio-Ferrezza, 2008, p. 132).

Later, in the 17th and 18th centuries, machine knitting in England gradually became a guild organized cottage industry (Vohra, 2008). By the end of the 18th century, the machine age of knitting was fully established (Gartshore, 1983, p. 92). In 1849, Matthew Townsend patented the latch needle in England. This latch needle made it possible for the circular knitting machine to run smoothly, thus making this machine viable in the production of weft-knitted fabric (Donofrio-Ferrezza, 2008, p. 132). The needle is still used in present-day machines.

Interestingly, the basic technology of modern knitting machines is similar to William Lee's earlier knitting innovation. Even the fully-fashioned knitting machine, invented in 1864 by William Cotton of Leicestershire, England, used the same bearded-spring needle, which was part of Lee's original design (Vohra, 2008). 'Fully-fashioned' is a term that is used to describe a type of knitwear production in which knitted fabric is produced for a garment according to its pattern shapes; for instance; the front body, back body, and sleeve pieces. William Cotton was responsible for designing over one hundred knitting machines, including circular knitting machines (Donofrio-Ferrezza, 2008, p. 132).

Power-operated knitting machines were invented in the 19th century (Knitwear, 2008). On the strength of the later developments of Lee's 16th century invention, England kept its leading position in manufacturing and exporting knitting machines until the beginning of the 20th century (Rasara Fashion World, 1992, p. 11).

Outside the UK, other countries developed knitting machinery in different ways. The first American flat bar knitting machine was developed in 1862 and patented in 1865 by the Rev. Issac Wixom Lamb, an American clergyman (Spencer & Knovel (Firm), 2001, p. 207). Within a few years, in 1873, Heinrich Stoll, a German engineer, began to build and repair Lamb knitting machines. As a result, Stoll founded a company bearing his name that continues today. Stoll developed the first motor-driven jacquard flat knitting machine in 1926 (Spencer & Knovel (Firm), 2001, p. 224). Gradually, Stoll, the company, improved their machine technology to include power-operated V-bed machines. Stoll has continued to play an important part in the development of V-bed flat knitting technology development to this day. On the other side of the world in Asia, the Japanese knitting industry began to embrace the Western concept of industrialization in 1871 when a group of Japanese businessmen went to America and returned home with a variety of knitting machines (Gartshore, 1983, p. 96). In Europe, in the early part of the 20th century, before World War I, Haute Couture houses in France, began adopting knits and made use of them in their Prêt-à-Porter collections by Coco Chanel who was the first designer to use jersey creating a loose fitting cardigan that became the style of the day. Chanel bought Rodier's entire stock of machine-knit jersey to overcome wartime shortage of textiles during World War I (Donofrio-Ferrezza, 2008; Moon, 1993). In 1951, the first 'International Exhibition of Textile Machinery' (ITMA) was in held in France. Since then, ITMA has been held every four years in different countries. This exhibition of textile machinery has been a focal point to the development of knitting machinery and knitted products (Rasara Fashion World, 1992 p. 11).

Building on the earlier adoption by the Japanese of American knitting machine technology, in the 1960s, the Japanese company Shima Seiki pioneered the development of automatic V-bed seamless glove knitting technology (Spencer & Knovel (Firm), 2001, p. 224). This development evolved and microprocessor-controlled seamless V-bed knitting machines accompanied by CAD systems came into existence (Spencer & Knovel (Firm), 2001, p. 136).

Computerized knitting

Machine knitting has progressed through different steps in the transition from simple machine knitting to computerized seamless V-bed knitwear manufacturing systems. The three main defining steps were from 'fully-fashioned' through 'power-operated', to 'computerized'. In parallel, there has been development of semi-integrated Computer Aided Design systems for designing knitwear and creating the knit data to enable knitwear designs to be manufactured using computerized knitting machinery.

Production of knitwear using computerized non-seamless V-bed knitwear design and manufacturing systems

There are presently five different ways under three main categories to produce machine knitted garment. These include '***cut & sew***': *fully-cut*, *garment length knitting*; '***shaping***': *fully-fashioned*, *integral garment knitting*; and ***computerized seamless V-bed production***. Each production type has its merits, limitations in production, and quality. A single production type may be solely or partially used throughout the knitwear production.

Cut & sew: fully-cut

This production type is done on mainly circular knitted fabric such as jersey. The knitted fabric is cut according to garment pattern shapes. Fabric loss can be 30%. Production is heavily dependent on labor and time; thus, it is suitable for low-cost mass production (Figure 13).

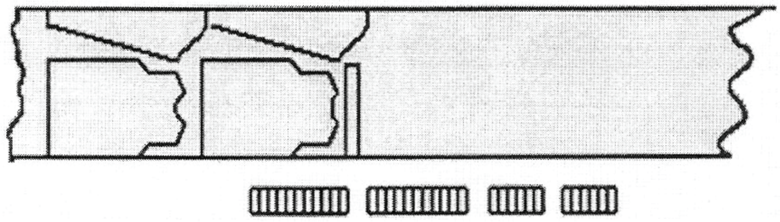


Figure 13: Fully-cut method of knitwear production. Source: (The Korea Federation of Textile Industries (KOFOTI), 2003)

Cut & sew: garment length knitting

Knitted fabric is produced according to a specific measurement; for example, the width of garment and the length of garment. Its fabric loss is less than that of the fully-cut method, and also assembling the side seams can be eliminated (Figure 14).

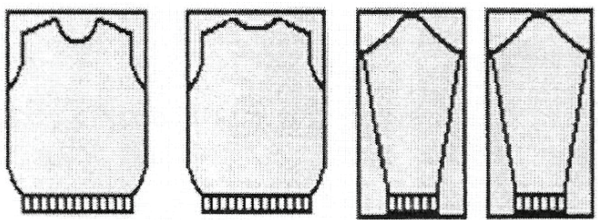


Figure 14: Garment length knitting. Source: (The Korea Federation of Textile Industries (KOFOTI), 2003)

Knitwear and garment shaping: fully-fashioned

Knitted fabric is produced according to its pattern shapes, for instance; front body, back body, and sleeves. There is almost no loss of fabric, but the knitting process is too difficult to speed up the production. Even so, it is the most popular of all types (Figure 15).

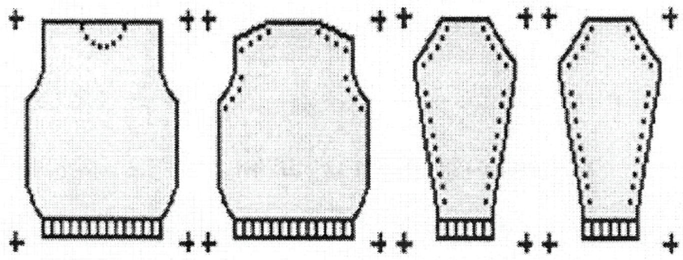


Figure 15: Fully-fashioned method of knitwear production. Source: (The Korea Federation of Textile Industries (KOFOTI), 2003)

Knitwear and garment shaping: integral garment knitting

This is an advanced type of fully-fashioned production. Design details like buttonholes, pockets, and necklines are knitted together with the body parts. As a result, there are less seamlines and; therefore, there is more body comfort. However, programming itself is too difficult to reduce production time (Figure 16).

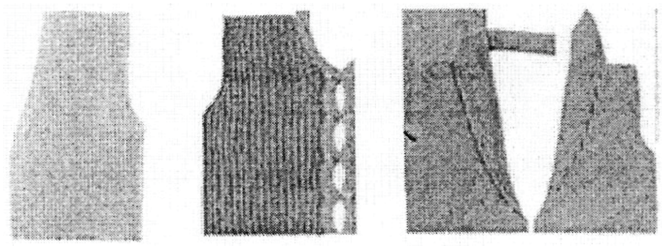


Figure 16: Integral garment knitting. Source: (The Korea Federation of Textile Industries (KOFOTI), 2003)

The researcher in her work as a knitwear designer has observed more than two decades of development in Computer Aided Design software for designing knitwear. Some knitwear CAD software is limited to providing visual support and guidance for the fashion designer in creating knit patterns and in some cases creating images of finished design. More advanced knitwear CAD software also creates the knit data to operate automated knitting machines. This latter software has developed over the last 20 years. It the early years, knitwear CAD software that created machine knit data required the designer to manually input knitting needle positions and stitch patterns stitch by stitch via a monochrome CRT screen. Currently, knitwear CAD software enables the designer on a full-color wide screen LCD display monitor to produce knit data for a garment at its simplest by choosing a garment type and using the software to scan fabrics or images and converting these scans directly into knitted fabrics or garments before knitting. With the application of computer graphics, the 1970s saw the introduction of CAD/CAM systems in apparel production – for example, designing, pattern-making, grading, marking, cutting, and stitching (Lee & Hwang, 1992, p. 98). Designers used the CAD system to create product designs and these were transferred to CAM machines to manufacture the final product. In knitwear design and production, this combination of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM), collectively known as Computer Aided Knitwear Design (CAKD), potentially revolutionizes the knitting industry.

For knitwear designers and manufacturers, the emergence of computerized knitting machinery was very significant because such computer technology enabled companies to respond quickly to changes in demand (Frings, 2002, p. 43). New designs were set up using CAD and quickly produced on the knitting machine. Computer technology also provided other advantages: it requires less supervision; simplifies the work of the machine and on the machine; and eliminates the need for many knitwear workers except for those skilled in CAD (Donofrio-Ferrezza, 2008, p. 139). In 1975, Stoll introduced the first fully electronic flat knitting machine (Spencer & Knovel (Firm), 2001, p.224). The use of electronics in microprocessor and computer systems replaced the mechanical patterning and shaping devices on the earlier knitting machines in which the electronics was limited to the controls. Electronics has specifically had its greatest impact in V-bed flat knitting because it enabled the use of advanced shaping of garments (Spencer & Knovel (Firm), 2001, p.137).

In spite of its costs and complexity, the new computerized knitting technology is preferred even though manually and mechanically operated, flat V-bed knitting machines are still widely used. Initially, the new computerized knitting systems were extremely expensive and only the major companies could afford them. However, in the 1980s and 1990s CAD/CAM knitwear systems began to fall in price to the point at which small and medium sized companies could invest in this new technology. During that time, Shima Seiki, one of the leading manufacturers of computerized flat knitting machines, has shipped over 80,000 since its first model was developed in 1978 (Shima Seiki Mfg., 2006). Two of the major benefits of this introduction of computer technology into knitwear design and computerized manufacture have been that it has enabled companies to operate globally, and not only in the lowest labor rate countries, and being computerized rather than purely mechanical has enabled companies to rapidly utilize computerized knitwear technology (Spencer & Knovel (Firm), 2001, p. 137).

Computerized seamless knitting

'Computerized seamless knitting' refers to the computerized knitting technology that enables the production of an entire garment in one piece without needing to join garment pieces together. There are two weft knitting machine technologies involved: circular knitting machines and V-bed flat knitting machines (see Figure 12). The approach eliminates several garment make-up processes, including cutting and sewing. This innovative computerized seamless knitting technology has increasing commercial applications in the knitwear industry throughout the world (Choi & Powell, 2005; Jung, 2004; Nam, 2004; Wilson, 2008).

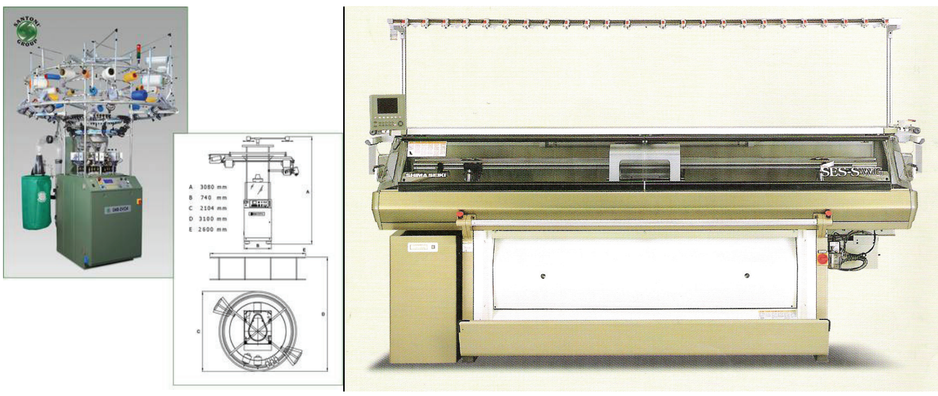


Figure 17: Exemplars of two different types of computerized seamless knitting machines. Source: (SANTONI SPA, 2009; Shima Seiki Mfg., 2009)

Seamless garments can be created by both circular and V-bed flat knitting machines (see Figure 18). However, seamless circular knitting machines are different from seamless V-bed knitting machines in that:

> *Seamless circular knitting machines such as Santoni create only a single tubular type of garment. Seamless flat knitting machines such as Shima Seiki can create more than one knitted tube at the same time and the tubes are joined together on the machine [(see Figure 19)]. The seamless garment knitted on the circular machines may also need minimal cutting and still require minimum seam joining on one body tube and two sleeve tubes as well as the finish the edges [(see Figure 20)]. Santoni has recently introduced a new machine, which shapes and eliminate the cutting*

process. Consequently, seamless knitting on circular machines is not true seamless knitting (Choi & Powell, 2005, p. 11).

Figure 18: Production of a sweater by computerized seamless V-bed flat knitting machine

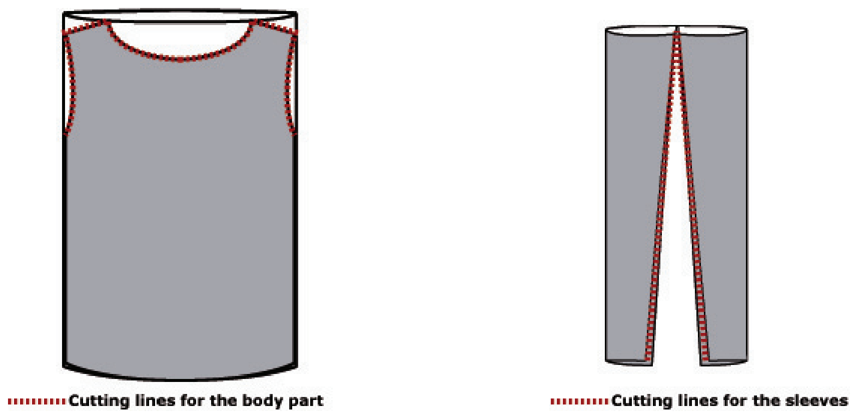


Figure 19: Production of a sweater by computerized seamless circular knitting machine 1

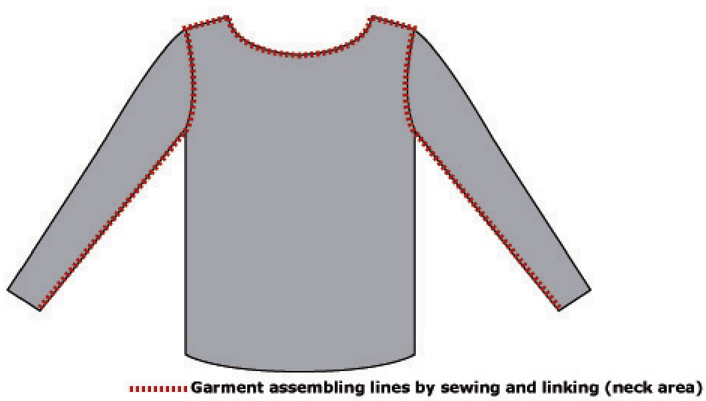


Figure 20: Production of a sweater by computerized seamless circular knitting machine 2

Computerized seamless V-bed knitting has a 200-year history following the development of circular knitting technology that was grounded in the problem of creating automated machines that would knit stockings, gloves and hats:

> *In the 1800s, the flat knitting used sinkers in order to knit items such as gloves, socks, and berets; in 1940, the 'flechage' technique was patented in the USA; in 1955, the automatic knitting of traditional berets through the shaped sections was reported; in 1960s, Shima Seiki further explored the tubular type knitting principle to produce gloves, and also, Courtaulds in the UK established British patents on the idea of producing tube garments by joining tubes. However, the method was too advanced to be commercialized at that time (Choi & Powell, 2005, p. 5)*.

The technology of computerized seamless knitting was introduced alongside earlier forms of CAKM knitting technology. Since the Renaissance period, cloth has been shortened and tightened, and eventually cut, pieced, and sewn together in attempts to bring into prominence the contours of the human form (Boyer, 1996). In the 1970s, companies researched more efficient technologies to produce a complete knitted garment, in one quick process without the need for sewing, and without the loss of fabric associated with '*cut-and-sew*' techniques. This was the intent of Shima Seiki's 'WholeGarment® technology', which was developed in the 1990s in Japan. Shima Seiki achieved this advancement in seamless knitting technology by applying the technique of knitting tubular courses of plain knit on a conventional V-bed flat machine. This novel approach to seamless garment design was undertaken in parallel with, and based on, knitting technologies that their engineers had developed for their knitting technology for the production of complete gloves on automatic glove knitting machines (Spencer & Knovel (Firm), 2001, p. 238). Similar pathways to development of computerized seamless V-bed knitting machines were undertaken by Stoll and others (Choi & Powell, 2005, p. 14).

Computer Aided Design, which began with 2D, and then 3D in the 1960s, moved into commercial use in the 1970s and became integrated with manufacturing processes as CAD/CAM in the 1980s (Bozdoc, 2003; Encarta, 2009; Jeong, 2001; Koh, 2003; Wallach, 2002). Presently, CAD/CAM technology virtually tests 3D modeling capacity as well as 3D loop simulation of WholeGarment® technology (Shima Seiki Mfg., 2008b). In other words, the technology virtually constructs a garment shape and the knit stitch patterns. Using dynamic simulation to create a virtual catwalk is also possible now (Jana, 2006). In textile printing, screen printing of one sort or another has dominated the industry since it was introduced into commercial use in Europe during the 1920s and 1930s and was at first a hand process (Harris, 1993, pp. 38-39). Advances in digital inkjet printing technology during the 1990s and early 2000s have resulted in knitting machines that can cost-effectively transfer designs directly from a computer and print onto fabric (Black, 2002, p. 106). For example, Shima Seiki's textile fabric inkjet printers apply design data created on their apparel design system, SDS-ONE® (Shima Seiki Mfg., 2007b).

For all knitting machine manufacturers, the development of computerized seamless V-bed knitting machines technology required a raft of new technical innovations of which one of the most significant was a redesign of the slide needle: developed to achieve perfectly symmetrical loop formation for knitting high-quality fabrics (Shima Seiki Mfg., 2008g). These slide needle innovations enabled knitting machines such as the Shima Seiki's SWG-First® computerized V-bed knitting machine to execute all of the three major types of knitwear production from fully-fashioned and three-dimensional shaping to seamless production (Choi & Powell, 2005, p. 21).

Garments created by computerized seamless knitting technology provide greater comfort than garments created via cut-and-sew methods. This is in part because the absence of seams means that the garment can stretch more easily and in part because they can be made to fit the wearer better and fit closer to the body. Computerized seamless garment knitting machines are also capable of producing complex designs. Knitwear design has been substantially limited by the reality that garments have been made from flat knitted fabric pieces. The use of computerized seamless knitting systems means that the use of flat fabric pieces is replaced by three dimensional knitwear that can be shaped and stylized as a single entity. The only significant drawback of this technology is that garments created on computerized seamless V-bed knitting machines are more open and less elastic than conventional fully-fashioned garments due to alternate needle selection (Choi & Powell, 2005, p. 29).

Fashion houses have globally paid attention to innovative computerized seamless knitting technologies since the success of the Santoni's seamless collection via an Italian designer 'Emilio Cavallini' in 2000. Santoni in Italy is one of the renowned electronic seamless circular knitting machine manufacturers. In 2001, one of official members of the Chambre Syndicale de la Haute Couture, Christian Dior, expressed its preference for seamless knitted tops to blouses (Korean Apparel Industry Association (KAIA), 2005, p. 35). Recently, Santoni and 'Emilio Cavallini' have been developing more high technology based fashion items in cooperation with major yarn producers – for example, Dupont and Nili (Korean Apparel Industry Association (KAIA), 2005, p. 36).

In spite of the early start in technology terms of seamless circular knitting machinery, computerized seamless V-bed knitting systems have advantages over circular machines in terms of ‘Fast Fashion’. Seamless circular knitting machines knit faster than seamless V-bed knitting machines. Seamless circular knitting machines are limited, however, in their ability to provide garments with shapes. This shaping ability is one of the primary advantages of the seamless V-bed knitting machine.

The computerized seamless V-bed knitwear technology is very similar across all manufacturers. As shown in Table 2, the computerized seamless V-bed knitwear systems of the two leading companies Shima Seiki and Stoll are similar in all aspects except needle types, even though each company claims their product is technically superior to the other.

Table 2: Comparison of computerized seamless V-bed knitting systems (Choi & Powell, 2005; Shima Seiki Mfg., 2008e; Stoll, 2008)

Features	Shima Seiki	Stoll
Name of seamless garment knitting technology	WholeGarment®	Knit&Wear®
Name of CAD systems	SDS-ONE®	M1plus®
Gauge	5~18 gauge	5~18 gauge
Knitting width	16”~80” (40 cm~203 cm)	72”~84” (183 cm~213 cm)
Knitting speed	Max 1.3m/sec	Max 1.2m/sec
Knitting systems	3~4 systems	3~4 systems
Yarn carriers	Up to 16 In case of knitting ‘Intarsia’, up to 30	Up to 16 In case of knitting ‘Intarsia’, up to 26
Racking	Max 3” total	Max 4” total
Take-down device	Main/sub take-down device	Main/upper take-down device
Transfer	Simultaneous transfer	Simultaneous transfer
Sinker system	Spring type movable full sinker system	Spring type movable holding-down sinker system
Needle selection	Electric selection system	Electric selection system
Needle	Latch needles, Compound needles, Slide needles	Latch needles
Term of various gauges on a single machine into a single fabric/garment	Gaugeless knitting	Multi gauge knitting

The use of computerized knitting garment technology to shorten 'time to market' in the fashion industry: 'Fast Fashion'

With the recent downturn of the global economy, mass retail consumers are now chasing mainstream fashion trends that offer almost the same products as the high-fashion houses, but made with less expensive fabric at much lower prices and with a short time between design and their availability to the retail public for purchase. This new trend has been referred to 'Fast Fashion'. The term is used to describe clothing collections based on rapid fashion design and manufacture at an affordable price (Answers Corporation, 2009; chosun.com, 2008; Jang, 2007; Tiplady, 2006). The term, 'Fast Fashion' may have originated with Alexander McQueen, the British fashion designer, who commented on the phenomenon, saying, "God, fashion moves fast" (Encarta, 1996). Europe is currently the Center of 'Fast Fashion' (for example, *H&M* in Sweden and *Topshop* in Britain). The 'Fast Fashion' trend has been growing in America (for example, *Forever21* and *Gap*) and is now also found in Asia (for example, *Uniqlo* in Japan).

The new 'Fast Fashion' pace of fashion design and production is now such that Zara, the fashion design house in Spain, can design and distribute a garment to market in just fifteen days (Ferdows, Lewis, & Machuca, 2004). New merchandise is displayed in Zara's shops in limited quantities and consumers are given a short window of opportunity for purchasing items. This motivates customers to visit Zara's shops more frequently than they might do with other stores. This short time between fashion trend design and market availability has resulted in innovation in fashion business practices, for example, it enables Zara to make a business and profit from of stock-outs (Ferdows et al., 2004).

'Fast Fashion' gains additional business competitive advantage because it builds on a timely flow of data back to designers and manufacturers from the retail stores via market information technology tools (Ferdows et al., 2004). Given this information, 'Fast Fashion' developments in the knitwear industry depend on the knitwear fashion house's abilities to design and manufacture knitted garments faster. Computerized seamless V-bed knitting machines offer a practical basis for the implementation of 'Fast Fashion' in seamless knitwear (Choi & Powell, 2005; SANTONI SPA, 2010). Seamless circular knitting machines are used in 'Fast Fashion' for *cut-and-sew* garments.

Total computerized seamless garment production is increasing steadily. It reached more than a 7% market share in 2003 compared to only 1% market share in 1997 (increasing at 1% per year); increasing with the new technological developments (Korean Apparel Industry Association (KAIA), 2005, p. 36).

In Asia, the heavy adoption of circular knitting machines and relatively cheap labor have contributed to the increase in 'Fast Fashion' as both factors tend to increase the pressure on rapid retail turnover of garments. This has environmental implications and the proliferation of the computerized circular knitting machine has played a large part in creating additional clothing waste both in terms of excess sales and waste resulting from the means of production (Garland, 2009). In contrast, the computerized V-bed flat knitting machine has almost zero waste from production because it enables garments to be created fully-fashioned and seamless in a single piece.

Using computerized seamless V-bed knitting technology well in 'Fast Fashion' requires, however, the resolution of the problem of integrating high-fashion designers into the computerized seamless V-bed knitted garment development process: the subject of this PhD research. The characteristics of the phenomenon of 'Fast Fashion' provide a succinct practical context for the problems that are the focus of this PhD and the significant implications for development of international knitwear sectors in retail, fashion design and manufacture.

Computerized seamless V-bed knitting systems and the research problem

It could be expected that, after 15 years of its release, there would be support or mechanisms in place for high-fashion knitwear designers to use computerized seamless V-bed knitting system for developing new fashion and garment sampling. However, despite its world-wide expansion into the garment industry, the technology has not accommodated high-fashion knitwear designers within its processes. The research will be focusing on Shima Seiki WholeGarment® knitting system as a typical example of this technology.

This oversight is the focus of this research because the computerized seamless V-bed knitting technology offers as yet under-developed potential in high-fashion knitwear. This research into high-fashion computerized seamless V-bed technology is significant, as some important fashion countries, for example, Italy and Japan, have started to make moves into the high-fashion knitwear market to compete with countries such as China, which is making inroads in the knitwear market by mass-producing products at low cost (Nam, 2004).

There has been, however, serious criticism of the interaction between the computerized seamless V-bed technical process and the high-fashion knitwear design process (Soong, 2006). The core problem is that, for reasons of speed, efficiency, and practicality, the knitwear development task has been divided between the knitwear designer and knitting machine technician, and the knitting machine operator has taken the development role. Knitting machine technicians typically compromise fashion knitwear designers' intentions in order to make a garment that is easier to program and faster and cheaper to knit.

Resolving the tensions between the knitwear designers and knitting machine technicians requires significant action, collaboration, and interaction in which neither understands the reasons for the others' actions or the language and concepts of the other. In many cases, interactions, essential to achieving good designs, do not happen at all. In addition, while computerized seamless V-bed knitting machines are relatively easy, though expensive, to obtain and knitwear designers are available to produce designs quickly, the process is hindered by knitting machine technicians in terms of rapid production of prototypes and the development of program codes for knitwear production. The following is Eckert's (1998) observation on the knitwear industry.

> *Knitwear design combines characteristics of fashion design and engineering. It is a variety of aesthetic design: sales depend on the appearance of the product. But there is a complex and subtle interaction between the appearance of a garment and technical properties that determine the feasibility and cost of producing knitted fabric. In consequence, the design process involves a problematic interaction between the knitwear designers who do the aesthetic design, and the knitting machine technicians who do a lot of detailed design in the course of programming industrial knitting machines to produce feasible affordable garments. The designers produce large number of designs, of which many are technically unfeasible, and only a few are selected for further development by technicians. Communication difficulties are aggravated by the pressure on designers and technicians to minimize the time between design research and production. Both have to work under intense time pressure, as the time from getting a brief to a hard delivery deadline is often short and the time required to produce a sample garment can be unpredictable. Thus, knitwear design shares many characteristics of engineering design processes, as well as of other aesthetic design processes.*

Knitwear design is subject to multiple constraints (see, for example, Petre, Sharp, and Johnson (2006, p. 185)):

- The nature of knitwear imposes particular design constraints because stitches are discrete forming a relatively coarse matrix that underpins the display of colors and textures of the yarn that produce the final appearance and shape of the garment or fabric;
- Choice of yarn (i.e., its weight and texture) constrains outcomes because of how yarns distort the knitted matrix in a variety of ways;
- Manufacturing introduces many constraints due to physical limitations of yarns, technical considerations of the machine knitting process, pressures to lower unit costs (and hence cost controls leading to limitations on yarns, numbers of colors, and even the development of new stitch patterns), and fast turn-around (with as many as six collections presented by any company in a single year). The design must be suitable to be knitted and then suitable to be worn;
- The computerized knitwear design process introduces constraints through multiple layers of explicit and implicit limitations in what designs are possible. In addition, the design process requires a significantly difficult integration bridging many differences in technical processes, information processes, and content and professional skills in engineering, business, management, craft, and art (Yang & Love, 2008). Because of the complicated nature of the computerized seamless V-bed knitwear design process, tension exists all the time between the two professions of knitwear designer and the knitting machine technician;
- Other constraints on design output occur due to communication difficulties between knitwear designer and knitting machine technician (see, for example, Eckert (1994)). These often begin as the knit designer prepares the sample design specifications sheet;
- There are constraints due to differences in culture between the professional groups. Knitwear designers are almost all young and female. On the other hand, knitting machine technicians are almost all male and usually older than the designers they work with. The average time a knitwear designer remains with one employer is about three years while a knitting machine technician remains at one company for a long time, often for his entire career; and
- Constraints on design output due to gender issues can occur at any stage in the process of melding design to technology. Senior male tutors who train designers on the WholeGarment® knitting system, for example, may believe that knitwear

designers do not care about the technology of the knitting machine. The designers want the end product only. As a result, designers do not understand the benefits that can come from a high technology knitting system such as the Shima Seiki. All the WholeGarment® system tutors are male. Only very few knitwear designers, who are primarily female, are interested in learning the latest knitting technology (Hirofumi, 2006; Seki, 2007). It is clear that the knitting industry has a gender divide along the technology boundary and this divide limits the creative design output.

An additional complication in discussing most issues relating to knitwear design is that the terminology in the knitwear industry is not universally accepted or defined. There are several different versions for terms. Certain terms may have different substitutes at different companies. Sometimes, terms learned at school become out-dated or graduates often lack the industry terms. In computerized seamless V-bed knitwear design, especially in the V-bed flat knitting industry in Korea, many Japanese terms and expressions are used. Some appear to be used in error. For example, when a tutor at Shima Seiki, who was native Japanese, was asked by the researcher, a few technical terms that were widely used in Korea, he was not aware of them (personal communication).

These issues of terminology, gender and age gaps can exacerbate what are often substantial communication difficulties between knitwear designers and knitting machine technicians and reduce the scope of creative design output.

A significant limiting factor is the way that particular roles have been defined in computerized knitwear design and manufacture. Roles have been highly segregated in ways that have a patriarchal technocratic flavor. As discussed earlier, the conventional roles in computerized knitwear design and production place the technician and operators (male) in control of the process and deprecate the roles of knitwear designer (female) This shapes the limits of how much of the knitting machine technician and knitting machine operator roles might be undertaken by a high-fashion knitwear designer in *1st sample* development process unless the design process to this point is changed radically. There is no position for a knitwear designer in the garment development process of creating computerized seamless V-bed knitting such as WholeGarment®. Without a well-defined workflow and practical exemplars of efficient ways of sample making, knitwear designers are overly dependent on knitting machine technicians and knitting machine operators. In effect, knitwear designers are blocked by the hurdle of managing the complexity of the WholeGarment® design software.

To learn operational skills on any computerized seamless V-bed knitwear design and manufacturing system requires training, and it appears that very few knitwear designers attend the relatively long-term residential training programs on programming made available by manufacturers.

Previous research into computerized seamless V-bed knitwear design and manufacture

The nature and type of research literature relating to computerized seamless V-bed knitwear design and manufacture is yet underdeveloped in comparison to fashion woven wear in all aspects. It is remarkable considering 400 year history machine knitting. Main causes appear to be sophistication of the technology and difficulty of accessing the relatively expensive technology. Other causes could be poorly practical, but too technically oriented literature. As Brackenbury (1992, p. 2) points out, there are very few books written about the knitting industry, most of those concerned with the primary process of knitting machinery and mechanisms, and not concerned the processes and divisions that define the production of knitted garments.

There are differences in the approaches to conducting research from nation to nation. PhD theses (Ki, 2006; Lee, 2008) produced in Korea are more technically oriented. Master's theses done in Korea (Jung, 2004; Nam, 2004), and other papers done outside Korea, focus on design development using this 3D seamless technology, reviewing the principles of WholeGarment® knitting technology, and the possibility of embedding the concepts of this knitting technology into existing curricular (Choi, 2006; Choi & Powell, 2005; Sayer et al., 2006).

Lee (2008) and Ki (2006) discussed ways of extending the potential envelope of creative design solutions in WholeGarment® knitwear. Lee experimented with different types and positions of narrowing on waist darts in a one-piece dress. She also tested the amount of underarm bind-off that affected the garment fit. Ki demonstrated the way to knit a WholeGarment® flared-skirt that offered a better appearance. Choi (2006) suggested another way of developing WholeGarment® knitwear via a resist dyeing technique. His design development approach was unique. This new direction was somewhat unexpected from an academic who had elaborated on the newest knitting technology, 3D seamless technology, in his previous journal articles (Choi & Powell, 2005). Regardless, Choi's application method for verification of the hypotheses suggested possibilities for extending the creative design envelope of computerized seamless knitwear by using other forms of 'textile art' or 'fabric manipulation' techniques with computerized seamless garment knitting on V-bed flat knitting machines. Choi's method has merit in that, by using designers who understand and appreciate the potential and constraints of the latest knitting technology, the ideas can be taken further. Similarly, Sayer, Wilson, and Challis (2006, p. 41) pointed out the benefits for designers to understand and appreciate the potential and constraints of the latest knitting technology. Nam (2004) and Jung (2004) dealt with the introductory level of WholeGarment® knitting technology and the contents of their papers were limited to listing advantages of using the 3D seamless technology in knitwear design development (Nam, 2004) and in knitwear production (Jung, 2004). Their papers were similar to Choi and Powell's (2005) with much less focus on the technical aspects.

Unlike other researchers, researchers from UK criticized the design approach embedded in Shima Seiki's WholeGarment® CAD system. In a journal article, Sayer, Wilson, and Challis (2006, p. 44) questioned the design validity of creating 3D seamless garments on the WholeGarment® knitting CAD system via 'predefined garment modules'. They regarded the WholeGarment® design method as a 'jigsaw approach' rather than a design approach and suggested it could aggravate the technology skills gap between designers and the potential of the machinery (2006, p. 44). Their term 'jigsaw approach' is used in this thesis to refer to the process of creating garment designs by modifying predefined garment modules and combining the outputs of multiple predefined garment specifications into a single complex garment pattern, in which virtual garment pieces (parts) are assembled by the 'designer' to create a garment of one complete piece.

Fashion designers and computerized seamless V-bed knitwear design

Fashion design using pre-registered garment shapes is more complicated than assumed. Going through all the pop-up menus successfully to the end step does not mean that the design will be successfully knitted on the machine. There is a kind of puzzle tournament waiting after that. The tournament is in easy or hard-mode depending on the designers' ability. However, some knitting technologists might not even consider 'WholeGarment® pattern making using pre-registered garment shapes' as programming at all because it is simply operating the automated garment development process using the prescribed software and its limited range of choices (Yu, 2009). The presence of 'predefined garment templates' (pre-registered garment shapes in Shima Seiki's term) seems to annoy many different groups of experts such as, researchers, knitting technologists, and fashion knitwear designers.

From experience in this research, the researcher disagrees that the use of pre-registered garment shapes aggravates any technology skill gap between the designers and the potential of the machinery. The researcher found that fashion designers could produce a very wide range of unique high-fashion garments by creatively modifying and combining predefined garment modules (see <u>Types of pre-registered garment shapes used to develop WholeGarment® designs</u> in Appendix 5 for details). This is also confirmed by Yang's earlier findings on the Combinatorics of fixed needle knitting using the Shima Seiki WholeGarment® knitting system (Yang, 2007).

Improving the number, range and quality of fabric pattern and predefined garment modules would, however, significantly improve the creative potential envelope for fashion designers. Designers possessing basic programming techniques would offer more possibilities in the creation of high-fashion knitwear. This then begs the question as to how designers would learn to program the knitting system and become proficient at it. From the researcher's perspective, it is an illusion to believe that the 'jigsaw approach' is less convincing on the grounds that it makes us feel like our clothes are being designed by a machine (Sayer et al., 2006, p. 44). Different types of experiences in different contexts-of-use generate different understanding about the use of the same product (Chamorro-Koc & Popovic, 2007, p. 144). Attitudes to whether fashion designers should create garments by modifying predefined garment modules or programming the garment modules from scratch depends on where the participant (user) stands. The same product (Shima Seiki pre-registered garment shapes) can make a big difference depending on whom (knitwear designer or knitting machine technician) is modifying them and to which level (novice or expert) in fashion design terms.

The researcher strongly believes that there should be different education pathways for high-fashion knitwear and knitwear art. The high-fashion knitwear pathway can provide the knowledge to overcome the technological 'design skill's gap' of the existing features by using additional creativity in programming the knitting system.

Several academic papers that are specifically about developing various types of sweater designs using WholeGarment® knitting technology were available to the researcher (Kim, 2003; Kim, 2004; Kim, 2005, Kim, 2006; Kim, 2006; Kim, 2007; Kim, 2007; Kim, 2008). The journal articles were primarily from a single research institute and were focused on technical issues rather than design issues. Although these research papers were helpful to understand the mechanism of the programming process of computerized seamless V-bed knitting, the shortage of practical user (i.e. fashion designer) understanding of the articles compelled the question to be asked about whether or not the researchers understood applied problems of these knitting machines. This dilemma reminded of the researcher McNiff and Whitehead's claim that (2006, pp. 64-65):

> *Privileged persons in elite institutions produce books and papers that present theory as an abstract discipline (Pring 2000). They also communicate messages that practitioners are not able to do research (McIntyre 1997). Practitioners come to believe these messages, and so develop informal discourses, that enter into professional discourses, about how they are not interested in theory because it is irrelevant and above their heads.*

This status quo can be seen as similar to that of present computerized knitwear industry: It is almost impossible to find a book or paper that combines knitwear designers' creativity with moderate technicalities. Either papers are too technical, or too basic. Knitting technologists appear to assume that knitwear designers do not like to work with machines because it is too complicated for knitwear designers to understand the mechanism. The outcome appears to be that many knitwear designers begin to believe this and this results in further restrictions on their role whenever more advanced technology emerges.

It is, however, unlikely and inappropriate for a fashion knitwear designer to learn and understand the technical details to program computerized seamless V-bed knitting machine to the same level of engineering technicality as a designer of the knitting machinery and its computerized management. Much of this knowledge is already embedded in the knitting system. There are non-engineering functions in the use of the system to achieve extreme complex fashionable garment shapes. For example, constructional garment details can be generated using various knitted structural patterns.

CHAPTER 4: Using the Computerized Seamless V-bed Knitting System – Workflow

The previous chapter provided the historical background to the development of the computerized seamless V-bed knitting systems that have resulted in a change in the way knitwear is designed and produced. The historical background illustrated how knitwear fashion designers have been substantially excluded from the fashion design process for knitwear that involves the use of computerized seamless bed knitwear technology. This is, in essence, an issue that relates to the design of the workflows, roles, tasks and information management processes and requires understanding these ways workflow and socio-technical processes dictate the involvement of fashion designers in high-fashion knitwear design using computerized seamless V-bed knitting technology. Before exploring these workflow and process issues directly, however, it is crucial to also understand the technical aspects of the computerized seamless V-bed knitting system and its software to have a basis to understand how these influence the workflow, task distribution and other processes. This knowledge also contributes to identifying opportunities possible for alternative workflows that more fully include fashion designers in the knitwear design process of computerized seamless V-bed knitwear design and production. This chapter describes the main technical considerations as seen by a user of the computerized seamless V-bed knitwear design and production system. It focuses primarily on those issues relevant to a knitwear designer wishing to use the system for high-fashion design using the design process and workflow developed by the researcher and described in later chapters. This chapter focuses only on describing the main technical operations of computerized seamless V-bed knitwear design through the example of the Shima Seiki SDS-ONE® system. The ways these technical aspects of the knitwear design shape the workflow is discussed in later chapters.

Computerized seamless V-bed knitwear design and production system

The system configuration comprises the two main components of the knitting system: the apparel design work station and the knitting machine itself (see Figures 21 and 22). These are separate units with the data from the apparel design workstation being manually transferred to the knitting machine. This is because a single apparel design station can produce knit data for multiple knitting machines.

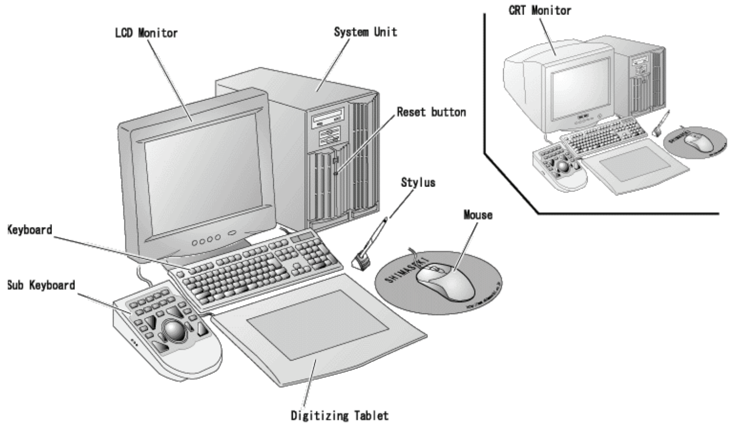


Figure 21: System configuration - apparel design workstation. Source: (Shima Seiki Mfg., 2008d)

The design of a knitted garment and its translation into the knit data files used to operate the knitting machine are undertaken in the CAD software located in the apparel design workstation. In the case of the Shima Seiki WholeGarment® system, this involves two programs *Design* and *KnitPaint* and the outcome is two files created through *KnitPaint* that can be loaded into the knitting machine controller to operate the knitting machine (Figure 22).

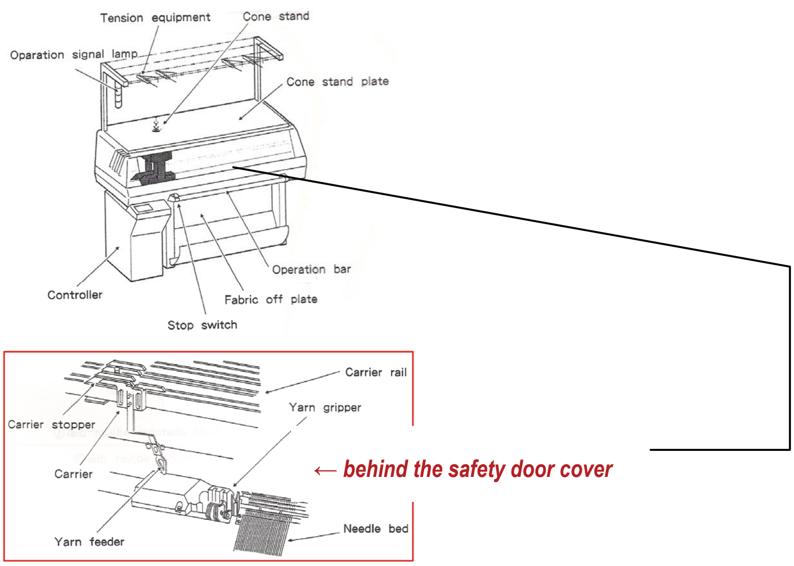


Figure 22: System configuration: knitting machine. Source: (Shima Seiki Mfg., 2008d)

The knit data files are copied to a portable memory device (floppy disk, CDROM, USB memory stick) which is then used to transfer the knit data to the knitting machine. The mouse and stylus pen, keyboard, sub-keyboard, and cursor are used in the apparel design workstation to guide software in ways that are very different from their use in conventional personal computer systems software. Clicking, double-clicking, dragging, and wheeling of the mouse lead to different functions to those common under Windows and Macintosh operation systems.

The actual knitting occurs on the knitting machine wholly separate to the design activity on the apparel workstation. The knitting machine stands around 2.5-meter-tall and 3-meter-long and uses the knit data files created by the *KnitPaint* software to operate the machine needles, yarns, tensions and other knitting machine settings and operations to knit the garment as designed. It has its own control computer system that can be hand programmed to change the machine settings specified in the knit data to, for example, compensate for differences in yarn characteristics and to resolve other knit problems in production.

The following section outlines and gives simple examples of the design of garments using semi-automated design for retail knitwear using computerized seamless V-bed knitwear system. It is followed by a brief review of how the details of a design appear in technical form as knit data generated by the apparel workstation and the ways this operates the knitting machine. The descriptions refer to the Shima Seiki SDS-ONE® system as a current state of the art of computerized seamless V-bed knitwear systems.

Design of garments using computerized seamless V-bed knitwear systems: Shima Seiki WholeGarment® system

At its simplest, the process of creating seamless V-bed upper garments is based on knitting three tubes (a body and two sleeves) which are joined at the underarm to form one tube at the shoulder, and decreased in width until the garment is bound off at the neckline (Sayer et al., 2006) (Figure 23).

Figure 23: Formation of a WholeGarment® sweater. Source: (Shima Seiki Mfg., 2008d)

Skirt designs are typically based on a single tube. Trouser designs are based on two tubes joined at the crotch to form one tube. Each of the two bottoms is decreased in width at the waist-hip until the bottom is bound off at the waist line.

The design of routine retail knitwear is done using pre-programmed patterns that allow some detail modification to shape plus the ability to add motifs and colored patterns to the knitted fabric. In the Shima Seiki WholeGarment® system these are called 'pre-registered garment shapes'. In this WholeGarment® system, routine seamless garments can be created through one of two approaches. The first is to choose the pre-registered garment shape and then create it in the intended size. The alternative approach is to specify the intended size of the garment (i.e. the size of the person for whom the garment is being created) and then choose the pattern of garment that will be created in that size. Choosing the 'size' first is a more user friendly approach for the designer.

Some examples of 'pre-registered garment shapes'

In the apparel design workstation of the Shima Seiki computerized seamless V-bed knitwear system, the 'Picture Directory' window indicates a choice of pre-registered garment shapes. These provide the basis for routine simple retail knitwear design. For high-fashion knitwear design, however, the routine approach to modifying these pre-registered garment shapes offers a very restricted creative fashion envelope than in effect only enclosed fashion solutions that are routine. Figure 24 illustrates some of these pre-registered garment shapes.

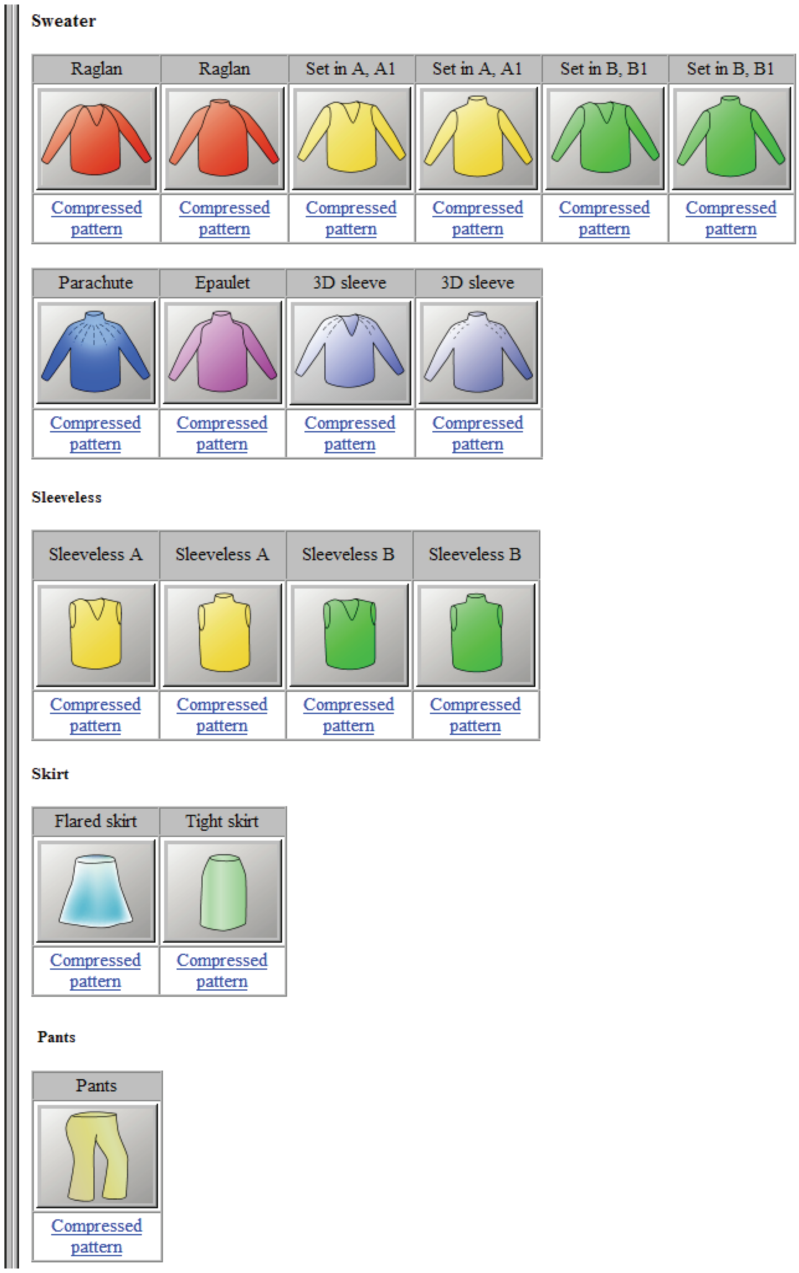


Figure 24: Pre-registered garment shape images shown in the Help File of *KnitPaint* (see, SDS-ONE® Help File, (Shima Seiki Mfg., 2008f)

The routine process of 'designing' garments using pre-registered garment shapes is described in the following two sections. The first outlines the range of options for variations to the design of a sweater. The second describes the design process for one particular design, the raglan sweater.

Range of options to create variants of a sweater

The main options for variants in the design of a sweater are the types of sleeve. *Raglan* sleeved sweaters have a shaped seam that curves diagonally from the armhole to the neckline or the front of the garment (Stecker, 1996, p. 144). Sweaters with *set-in* sleeves have the sleeve as a separate piece of knitted fabric inserted into and attached to the armhole of the body of the sweater (Stecker, 1996, p. 144). There are several different kinds of s*et-in* sleeve arrangements. They differ depending on the proportions and shapes of the knitted sweater body and sleeve at the joint line and these change the shape of the sleeve, armhole and sleeve cap in several ways. Different examples are listed in Table 3 below. In addition, the Shima Seiki WholeGarment® machine used in this research offers three other sleeve to body arrangements, which they named *Parachute*, *Epaulet*, and *3D sleeve.* The *Parachute* arrangement makes no distinction between the armhole on the body and sleeve. The body is composed of trapezoid parts (panels), which are arranged in a fan-like form. In the E*paulet* body to sleeve arrangement, the front shoulder drop is the same shape as the back and has wide bind off knitting performed on the shoulder part. In contrast, to the sleeve to body join arrangements that emphasize the visual lines of the join, in the *3D sleeve* arrangement, the body and sleeve are not distinguished and the body and sleeve flow smoothly together with the silhouette and shoulder shape created by shaping the body and sleeve 'tubes'. *Sleeveless* garments have a finished arm hole without a sleeve and this opening can be arranged/detailed in several different ways similar to the body arrangement for *Set-in* sleeves. These options are listed in Table 3 along with options for neckline and collar with supported features indicated by a '√'.

Table 3: Available styles under different garment shapes

Garment shape	Style	Neckline		Collar	
		U-Neck	V-Neck	Collar attached	Collar knitted
Sweater with sleeves	Raglan	√	√		
	Set-in A	√	√		
	Set-in A1	√	√	√	√
	Set-in B	√	√		
	Set-in B1	√	√	√	√
	Parachute	√			
	Parachute 1				
	Epaulet A	√			
	3D Sleeve	√			
Sleeveless sweater	Sleeveless A	√	√		
	Sleeveless B	√	√		

Ordinary users following the conventional pre-registered garment design approach can manipulate the length and width of pre-registered garment shapes to a very limited degree. The limits result from the knitting system being built for manufacturing purposes rather than for individualistic extreme fashion.

This almost completely automated design approach is so limiting for high-fashion designers that Sayer, Wilson, and Challis (2006, p. 44) questioned whether or not the process of mix and match with 'predefined garment modules' could be even called design. They claimed this 'jigsaw approach' resulted in a significant gap between fashion designers and the potential of the computerized seamless V-bed knitwear design and manufacturing technology.

Creating a raglan sweater: design and manufacture

The creation of a retail raglan sweater is the first topic a trainee encounters when learning how to create a garment using Shima Seiki's WholeGarment® computerized seamless V-bed knitwear system. Two different types of software and 38 operational steps are involved in the garment design and production process (although Shima Seiki has mysteriously reduced the process to 10 steps in their Help file).This type of sweater is the easiest to design as it only requires accepting the default values of settings at every stage in the design and manufacturing process. That is to say clicking 'OK' or 'Execute' repeatedly and not accessing any input boxes or changing any of the knitting or garment variables. Using the *KnitPaint* software, the design process for the Raglan sweater can take as little as 2 minutes on a high specification computer, although it may take a little longer using a computer of lower specifications depending on the computer specifications. After the design is completed, 10 additional steps using the *Design* software result in confirmation using the garment's virtual simulation. This takes approximately 4 minutes. Theoretically, an inexperienced user of the software can produce a WholeGarment® raglan sleeved sweater in less than an hour, including design and knitting time. The following Table 4 describes the process:

Table 4: The steps in creating a WholeGarment® raglan sweater

<table>
<tr><th>Steps</th><th>Software</th><th>Minutes</th></tr>
<tr><td>File: on main menu bar
New window
Picture Directory
Gauge Input
Information
Size Input
Information
Edit Pattern of Narrowing (AH: Front)
Edit Pattern of Narrowing (AH: Back)
Edit Pattern of Narrowing (AH: Sleeve)
Initialize & Outline Adjust
Doubling Set
Slide Process
S·Paint blinking
Warning Now Saving
Confirm
Processing Package Development: Partition Order Draw
Processing Package Development: Package Development
Processing Package Development: Package Pat. Gather Up
Processing Package Development: Package Order Draw
Automatic Software Settings
Area
Auto Process Parameters
Processing
Output Data
Knit Simulations>Simulation Start
Knit Simulations >Loop Simulation
Simulation Start>No Error Found</td><td rowspan="2">KnitPaint</td><td>2</td></tr>
<tr><td>Loop Simulation window</td><td rowspan="2">2</td></tr>
<tr><td>Making the Connecting Information
Knit Loop Simulator
Now Loading File</td><td>Transition occurs from KnitPaint to Design</td></tr>
<tr><td>Loop Draw
Yarn Setup
Processing</td><td rowspan="2">Design</td><td>1</td></tr>
<tr><td>Loop Draw
End
Make Shadow</td><td>1</td></tr>
<tr><td colspan="2">Time required in total</td><td>6</td></tr>
</table>

The above gives a simplified example of the Shima Seiki workflow. The basic general operational steps for computerized seamless V-bed knitwear design and manufacture are composed of two parts: the creation of design on the CAD system and operation of the knitting machine. The general process, omitting the complex of detailed steps undertaken by the knitting machine technician, or in the process developed in this research by the knitwear designer, comprises:

1. Turn the CAD system on.
2. Create a new pattern which can be a seamless knitwear piece or fabric (14 or 8 gauge)
3. Convert the created pattern into the machine data (knit data)
4. Save the knit data.
5. Turn the knitting machine on.
6. Load the knit data from the CAD system.
7. Operate the knitting machine.
8. Turn the CAD system and knitting machine off

In addition, there are several specific procedures undertaken by the knitting machine operator

1. Transfer the knit data to the knitting machine using an MO disk or USB device
2. Check the stitch data, take down data, and yarn adjustment data settings to see that they make sense in terms of the garment and yarns.
3. Prepare of the yarn carrier and fabric settings.

Where there are problems with the 'knit-ability 'of a garment design, either in the CAD process or the knitting machine processes, error messages show the faults and identify the location in the system in which the fault occurs. These include, for example: yarn, needle, twining around, shock, finish, stitch presser set error, safety cover, and needle selection timing error. Examples of knit-ability problems and their location are shown in Table 5.

Table 5: Examples of knit-ability problems and their location. (Shima Seiki Mfg., n.d.-b)

Error message	Possible causes	Things to do
Yarn	Yarn breakage or knot of yarn is detected or yarn feeding roller cover is open.	Reset the yarn and devices to the point they were at before. Then remove the error by keying F2 or turning the operation bar.
Needle	Fabric rises due to the broken needle or yarn feeders stop too closely.	Check the followings when fabric rises: breakage of needle, stitch value, knitting program, and take down value. Adjust yarn carrier's stop position with 'yarn carrier reset adjustment data' when feeders stop too closely; feeders must be at least two needles apart.
Twining around	Fabric or yarn is wound around the main roller.	Check the gap between the main roller and 'fabric detecting plate' when the error occurs often.
Shock	Jack breakage is detected or sensitivity of shock sensors is	Replace broken parts with new ones or adjust sensor sensitivity.

	high.	
Finish	The setting value of a piece counter is completed.	Set the piece counter to '000' or set a larger value for piece setting.
Stitch presser set error	A stitch presser in action touches the feeder.	Firstly, check 'yarn feeder reset adjustment data' and then 'carriage stroke adjustment data'.
Safety cover	The safety cover is opened; it is not detected under 'ultra-low-speed'.	Close the safety cover.
Needle selection timing error	The carriage is moved by hand.	Make the machine to the original setting and start from the beginning.
No Auto Yarn Feeder Point (A.Y.F.P.) in pattern data · A.Y.F.P. number error	There is a mistake in the pattern of automatic software.	Check auto yarn feeder points (color number 13) and pattern development data on SDS.

Occasionally, and on complex high-fashion garments not so occasionally, the knitting process can fail completely and dramatically. In this case, the best option from experiences is to abort the garment rather than try to change the knitting machine settings and attempt to continue to knit. This involves stopping the machine, removing all traces of the garment being knitted and then turning the machine off and restarting it from scratch.

Function and formation of knit data

When a garment is designed using the software on the apparel design workstation, two forms of knit data are created: differentiated by two types of files and two different file extensions: *.000 and *.999. One of the files contains the actual knitting of design created on the CAD system and the other the information for the settings of the knitting machine. The computer embodied in the knitting machine controller then uses this knit data to operate the knitting machine itself. There is also a default version of the *.999 data file that can be created and this is used as the basis for manually adjusting the settings on the knitting machine via a main menu screen and keypad on the small screen of the controller to suit different physical properties of knitting yarn. The knitting machine has multiple settings and processes of which some (shown in green on the image of the knitting machine below in Figure 25) are managed by the *.000 file. The other settings and processes (shown in red boxes) are managed via the *.999 file.

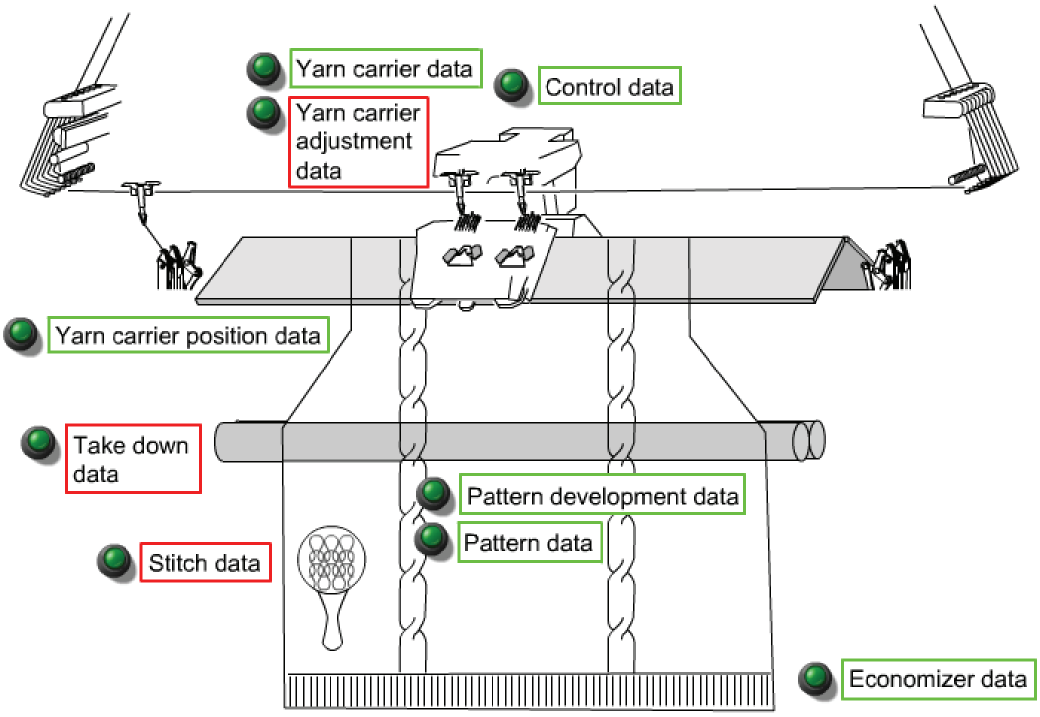


Figure 25: Main knit data. Source: (Shima Seiki Mfg., 2008c)

The main data information in the knit data files are listed in Table 6.

Table 6: Main data held in .000 and .999 knit data files

Data type	Controlled data	Function
*.000 file	Yarn carrier data	commands which yarn carriers to be used
	Control data	adjusts stop positions of yarn carriers
	Yarn carrier position data	commands where pattern is to be placed in the horizontal direction
	Pattern development data	commands pattern
	Pattern data	commands how to knit and how to use all other data
	Economizer data	commands repeat number when same knitting is to be repeated
*.999 file	Stitch data	commands size of stitch
	Take down data	adjusts take down tension when knitting
	Yarn carrier adjustment data	commands starting carriers position

As outlined earlier, the knit data files are created using the SDS-ONE® apparel design workstation via the *KnitPaint* software either from simple designs created in the *Design* software or for more complex designs, created directly using the technical facilities of

KnitPaint. These knit data files are used for both virtual knitting (3D simulation) on the CAD system and actual knitting on the knitting machine.

The software engineers who produced the Shima Seiki *KnitPaint* software, creatively named the main initial drawing of a fabric or garment, "the 'original drawing'". In this 'original drawing', the intended stitch pattern design is represented by unique colors for each stitch with each color and kind of stitch having a unique 'color number'. For example, a single normal knit stitch is represented by a single red square (color number 1) similar to a pixel on an image. In consequence, one row of knit stitches is represented by a horizontal red line. Similarly, a row of the purl stitches is represented in the 'original drawing' by a horizontal row of green squares (color number 2). Figure 26 serves to illustrate how alternating rows of knit and purl stitches (garter stitch fabric) is shown in an 'original drawing' in *KnitPaint*. The stitches are shown on the left with the representation of the knit data as colored squares shown on the right.

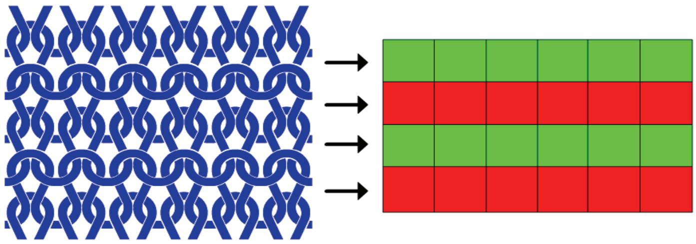


Figure 26: The stitch pattern vs. color codes. Source: (Shima Seiki Mfg., 2008d)

Similarly and slightly more complex is where a section of normal knitting is followed by a section of 'rib' knitting. This situation is commonly found at the waist and cuffs of a sweater. In a rib section, the knit and purl stitches alternate on the same line. Figure 27 below shows a section of rib drawn below a section of normal 'garter' stitch pattern fabric. Ribs can have many variants depending on how many knit and purl stitches alternate. For example, ribs might be a simple combination of one knit stitch followed by one purl stitch followed by one knit stitch etc (1x1 rib). If two knit stitches are followed by two purl stitches followed by two knit stitches etc then this is a 2x2 rib. Other common rib combinations include 2x1 rib and 3x3 rib.

Figure 27: Rib drawing (1 x1 rib below a panel of normal garter stitch pattern fabric). Source: (Shima Seiki Mfg., 2008d)

Computerized seamless V-bed knitting machines cannot simply start knitting. They require a special starting process called a ‘Fixed Rib’. This ‘Fixed rib’ starting sequence must be added to the ‘original drawing’ that represents the knitted garment on the first and second lines from the bottom. It is shown on the ‘original drawing’ as a special red, green, yellow, and blue color sequence (Figure 28).

Figure 28: Fixed rib data added to a section of rib knitting beneath a section of garter stitch pattern knitting. Source: (Shima Seiki Mfg., 2008d)

Similarly, another special indication is needed to instruct the machine to ‘cast off’ the knitting when the knitted piece is complete in such a way that the knitting does not unravel. For the example described above, the ‘Cast-off Fixed Data’ is added to on the top line of the stitch pattern as shown in Figure 29.

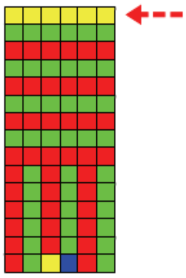


Figure 29: Cast off fixed data drawing added to the top of a sample knitted piece. Source: (Shima Seiki Mfg., 2008d)

In practice on the knitting machine, the width of knitted fabric is defined on both left and right side by the knitting carriage moving to left and right and right to what Shima Seiki has called the ‘Auto Yarn Feeder Point’, which specifies both ends of the stitch pattern and hence the width of the fabric. In the visual knit data representation, the left and right bounds of the fabric are indicated by adding gray (color number 13) ‘Auto Yarn Feeder Point’ squares to the left and right is shown in Figure 30.

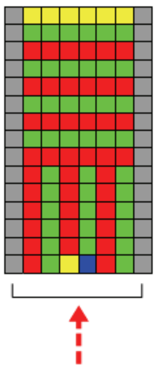


Figure 30: Adding gray (color 13) Auto yarn feeder points to the left and right of the fabric as shown on the ‘original drawing’. Source: (Shima Seiki Mfg., 2008d)

Defining the boundaries (four ends: bottom, top, left, and right) and knit stitches in the fabric or garment completes the development of the information about the fabric or garment itself.

The settings for the knitting machine settings are also defined on this same visual display as the above information about the knitted stitch patterns of the fabric or garment. The settings use the same concept of colored squares aligned to the rows of knitting. In the case of the knitting machine settings, these are called 'Option Line Bars'. The 'Option Line Bars' are visually located on either side of the information about the stitch pattern as shown in Figure 31.

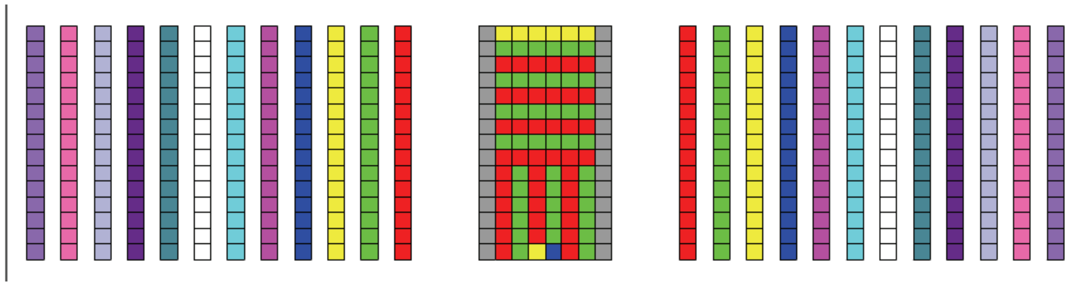


Figure 31: Option Line Bars either side of the knit stitch data. Source: (Shima Seiki Mfg., 2008d)

A set of default vales for the 'Option Bars' are automatically generated when creating 'New' files for fabric or garment designs. These settings can be adjusted using the *KnitPaint* software and some of them can be changed manually on the knitting machine's control console.

One of the most commonly used option bar is the 'Jump Economizer'. This option specifies the number of time a number of rows of knitting are repeated. The jump economizer option bar is located immediately to the right of the stitch pattern information on the 'original drawing'. It specifies both the number of repeats (entered in the 'Auto Screen' of the knitting machine controller or in 'Automatic Software Processing' screen of the SDS-ONE® *KnitPaint*) and is visually located at the side of the rows that are to be repeated as shown in Figure 32.

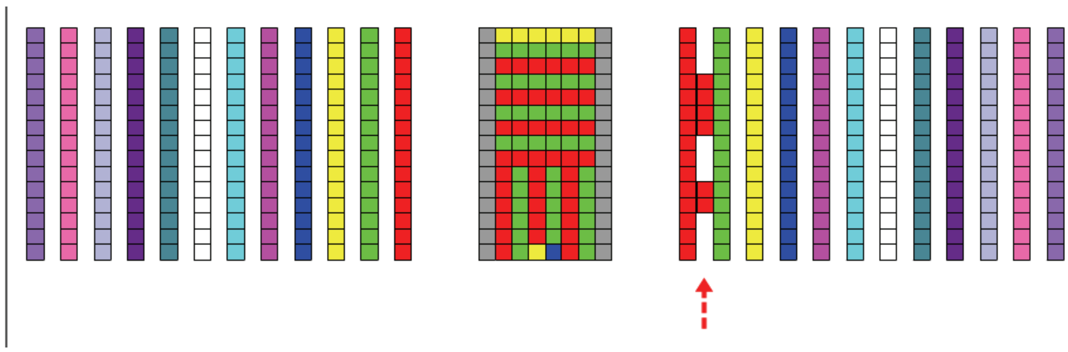


Figure 32: Jump Economizer. Source: (Shima Seiki Mfg., 2008d)

Another commonly used option is that which tells the knitting machine which yarn to use. Each different yarn used in a fabric or garment is delivered through its own yarn carrier. The simplest garment uses a minimum of four yarn carriers: two for the fixed rib, another for special melt-able yarn used to finish the last row of the knitting, and the last is for the main yarn used for the knitting. More complex garments involving (say) jacquard or complicated knit structures and multiple tubes will be knitted using several yarn carriers. The 'Yarn Carrier Change' option bar specifies when the yarn carrier (and yarn) is changed while knitting. It is indicated on the 'original drawing. Typically, the color number of the yarn carrier option is as same number as the yarn carrier number. Figure 33 shows the use and change points of two yarn carriers (and yarns) between yarn carrier number 6 (light blue) and number 4 (mid-blue).

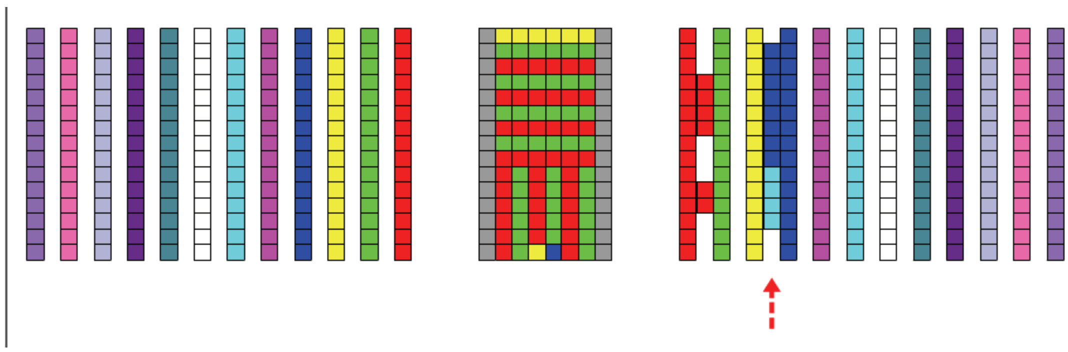


Figure 33: Yarn Carrier Change Option Bar. (Shima Seiki Mfg., 2008d)

Another important machine setting specifies the length of each knitted loop. Long loops result in loose knitting and short loops result in tight knitting. Correct loop length is important also for knit-ability. If the loop length is too long or short then the knitting action can fail leading to holes or snags. The 'Loop Length Number' specifies the length of the stitch loop. The Option Bar for the 'Loop Length Number' is indicated right next to the sixth bar on the right end of the pattern (R6). The 'Loop Length Number' is set either in the *KnitPaint* software or on the knitting machine console and in both cases is allocated to a color number that it itself specified in terms of the part of the fabric/garment that is being knitted. For example, color number 5 (pink) is usually associated with knitting for indicating the length of stitch for the body part of a garment. In Shima Seiki's terminology, the 'body' of a garment refers to all the main knitting areas of a fabric/garment except the rib, fixed rib, and cast-off. Figure 34 shows eight lines of garter stitch pattern that is part of the body of a fabric marked for which the 'Loop Length Number' has been allocated to color number 5 (pink). The diagram also shows different Loop length numbers have been allocated for row ending the rib (blue) and the rib itself (gray).

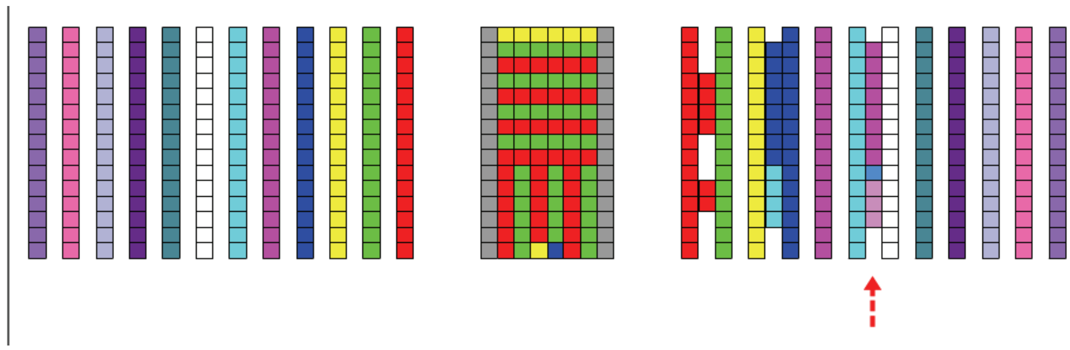


Figure 34: Loop Length Number. Source: (Shima Seiki Mfg., 2008d)

The knitting area if confined and restricted in terms of the number of devices that can occupy the knitting space. When yarns are no longer being actively used for knitting then the yarn and yarn carrier associated with that yarn are moved out from the knitting area. When a different yarn is needed, its yarn carrier is moved into the knitting area. These movements of yarn carriers into and out of the knitting area are controlled by the 'Yarn In' and 'Yarn Out' Option bar instructions on the 'original drawing'. The 'Yarn out/Yarn in' options move the carrier from the gripper device to the knitting area and vice versa. The 'Yarn out/Yarn in' options are indicated next to the eighth bar on the right end of the pattern (R8) (Figure 35).

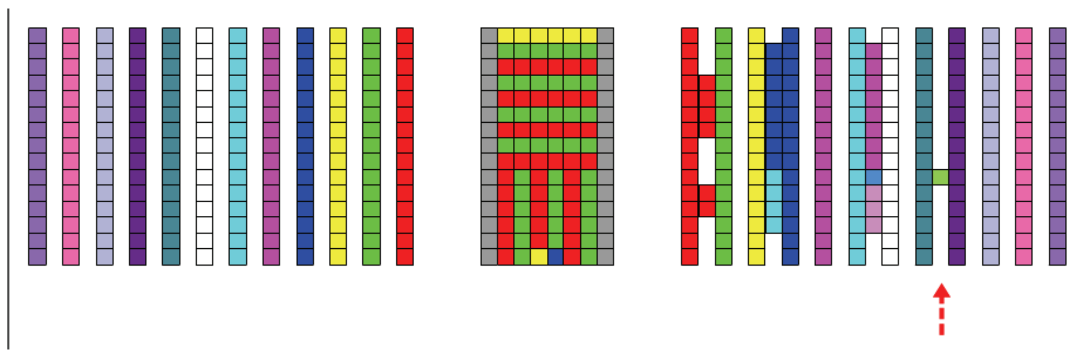


Figure 35: Yarn out/Yarn in Option Bar. (Shima Seiki Mfg., 2008d)

The loose end of an active yarn needs to be held secure to be cut cleanly to start the knitting process. The gripper device automatically grabs yarns to be used when begin knitting and holds the yarns to be cut when completing knitting. This holding of the yarn by a yarn gripper is activated by the 'Gripper' Option. The 'Gripper' Option is indicated next to the tenth bar on the right end of the pattern (R10). Figure 36 below shows the gripper being used at the changeover from rib to body knitting.

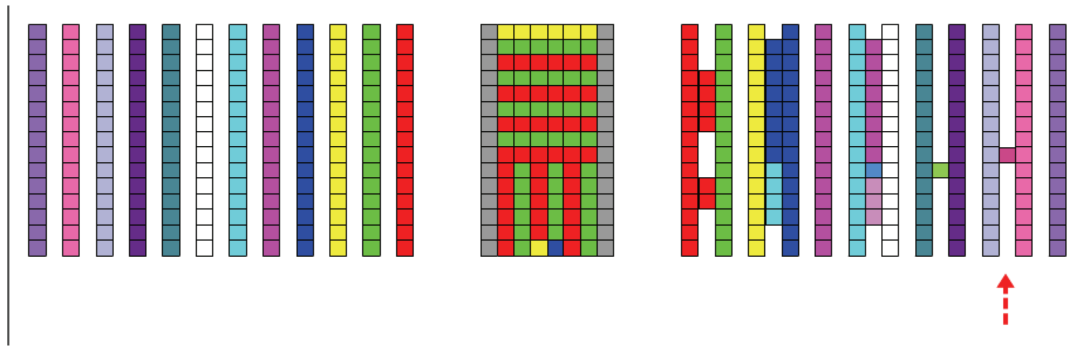


Figure 36: Gripper Option Bar. (Shima Seiki Mfg., 2008d)

Some forms of knit structure require the stitch loops on the needles to be pressed down to restrain them. This is done by a simple bar that is activated on and off by the 'Stitch Presser' Option. The 'Stitch Presser' holds down the old loop while the knitting needle is raised and new yarn is threaded. It stops the old loop from dropping off. The 'Stitch Presser Option Bar' is located next to the eleventh bar on the right end of the pattern (R11). In Figure 37 below, the 'Stitch Presser' is activated (on, red) for the knitting in the body part and off (blue) for the rib section.

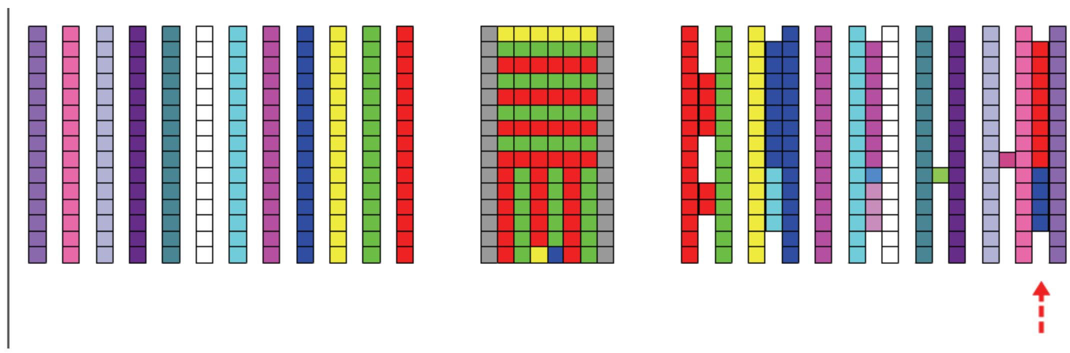


Figure 37: Stitch Presser Option Bar. (Shima Seiki Mfg., 2008d)

While knitting a fabric or garment, the knitting machine tensions that already completed knitting and pulls it downward away from the knitting area. This is done by rollers. The tension on the knitting delivered by the rollers, the main roller and sub-roller, is known as the ‘Take Down’ and represented by the ‘Take Down’ number. There are two knitting courses that each has its own ‘Take Down’ number: the knit course and the transfer course. The ‘Take Down’ numbers for both courses are controlled by the ‘Take Down’ number Option Bars indicated next to the tenth and eleventh bars on the left end of the stitch pattern (L10/L11). L10 is for the knit course and L11 is for the transfer course which requires less take down tension than for the knit course. Figure 38 shows both.

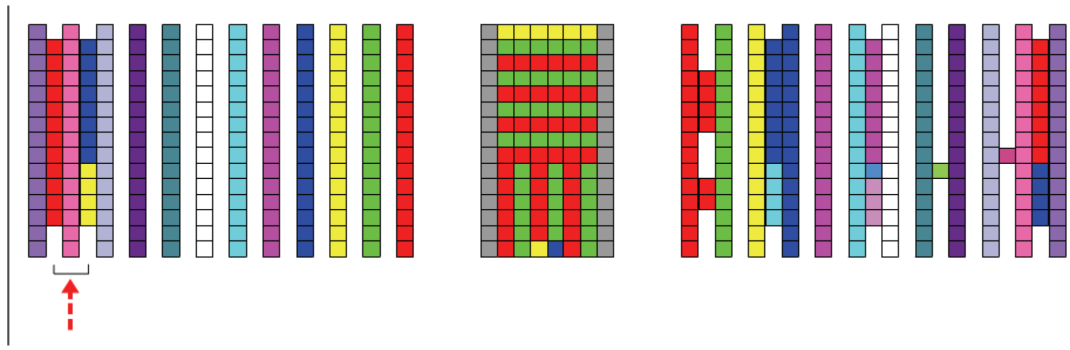


Figure 38: Take down number. Source: (Shima Seiki Mfg., 2008d)

Each needle on the knitting bed is specified by a needle number. The knitting bed of the NewSES183S•WG WholeGarment® knitting machine has 1008 knitting needles on both beds. On the manufacturer’s advice, however, the first and last groups of needles are rarely used. Instead the knitting is commonly started at needle number 11. A similar number of needles are unused at the other end of the knitting bed and in most cases, these needles are used so rarely that they are not even fitted. The number of the first needle on the knitting bed that is used for knitting is known as the ‘Starting Needle Number’. The ‘Starting Needle Number’ Option Bar specifies the needle number to begin the knitting counting from the left end of the needle bed. The ‘Starting Needle Number’ Option Bar is indicated above and in-between the first and second bars on the left end of the pattern. The ‘Starting Needle Number’ is indicated by a color number. Figure 39 has the ‘Starting Needle Number’ indicated by color number 11 (dark pink) which specifies that knitting starts from the 11th needle on the left side of the knitting machine.

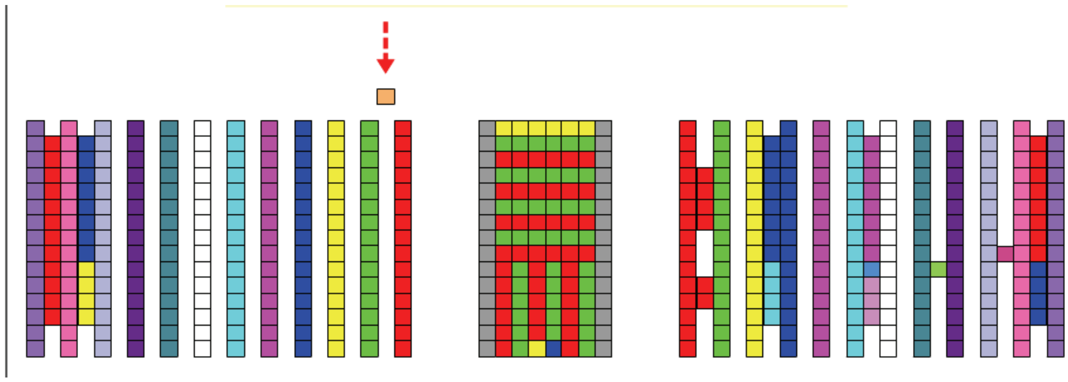


Figure 39: Starting Needle Number Option Bar. (Shima Seiki Mfg., 2008d)

Some knitting patterns repeat horizontally across the fabric or garment. The Shima Seiki terminology for this horizontal repeat option is 'Pattern Development'. The 'Pattern Development' Option Bar specifies the area to be repeated. It is indicated above the section of the stitch pattern. Color numbers indicate the number of repeats of the wales (vertical rows of the stitch pattern) below each color, e.g. blue squares (color number 4) results in 4 repeats of the wales below them. Figure 40 shows a pattern development without horizontal repeats. The color number 1 (red) means one pattern i.e. 'no repeat'.

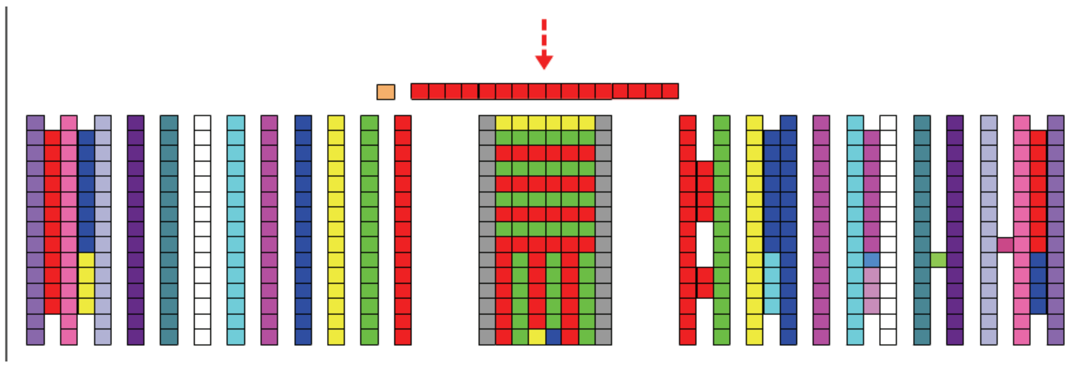


Figure 40: Pattern Development. Source: (Shima Seiki Mfg., 2008d)

Once these and other knitting machine settings, and the knit structures are satisfactorily marked on the 'original drawing', the *KnitPaint* Automatic Software settings menu item can be used to automatically generate the two knit data files, with the *.000 and *.999 suffixes as described earlier. These two knit data files can then be copied to a USB device to transfer them to the knitting machine controller ready for knitting the fabric or garment.

CHAPTER 5: Workflows of Computerized Seamless V-bed Knitwear Design and Manufacture

This chapter reviews the literature and background contextual issues relating to the multiple workflows involved in the different forms of knitwear design and production. This review of workflow processes provides an empirical and conceptual backdrop to the problems found by knitwear designers, particularly in the area of high-fashion, that have emerged with increasing technologization of knitwear design and manufacture, particularly as they relate to computerized seamless V-bed knitwear design and production.

As discussed in the earlier chapters, the workflows, authority paths, knitting design information handovers and professional processes work against the useful participation of knitwear designers in creating high-fashion outcomes. The reason is a significant disjoint between traditional high-fashion design processes and the mass-market retail knitwear development processes of computerized seamless V-bed knitting systems. Current commercial computerized seamless V-bed knitting processes reduce garment design to simple selection of garment shapes and details from a small range of standard garment styles, or highly technical re-programming of the knitting machine programming by engineers (see, for example, Shima Seiki Mfg., 2008d).

This is problematic in both cases because it blocks the possibility of creative input from high-fashion knitwear designers to create high-fashion garments using this technology. This presents a significant missed opportunity because the computerized seamless V-bed knitting technology otherwise offers the triple benefits of seamless garment production, rapid prototyping and garment sample making, and a direct path to rapid local mass manufacture of high-fashion knitwear (i.e. Fast Fashion) because the knit data files for new high-fashion garments can be easily and quickly distributed over the internet. The limiting factors are the absence in current processes of computerized seamless V-bed knitwear systems of appropriate roles and workflows that fully incorporate high-fashion knitwear designers as the main focus of the design stage of knitwear development, and appropriate design methods that enable these fashion knitwear designers to operate the computerized seamless V-bed knitwear technology within a sufficiently large envelope of creative possibilities.

At the start of this research, the researcher speculated that there would likely be different workflow pathways to high-fashion knitwear and knitwear art using computerized seamless V-bed knitting technology than those currently optimized for fast mass-market retail garment production. This was borne out by the research findings as a result of undertaking multiple knitwear design projects during the course of the research. The outcomes of the research indicated that solutions can be found that do not require complete re-devising of the computerized seamless V-bed knitwear design software and processes, but rather, require different workflows and different design methods for creatively using the knitting system to extend its envelope of potential solutions to include those suitable for high-fashion whilst remaining within the skill competences and of fashion designers.

Socio-technical system perspective on computerized seamless V-bed knitwear design and manufacture

The researcher chose to view computerized seamless V-bed knitwear design and manufacture as a socio-technical system (STS)(Trist & Ontario Quality of Working Life, 1981). Locating the research at the socio-technical system nexus provides a meaningful way to simultaneously include issues to do with individuals, professional roles, workflows and work processes, professional groups, technical issues, technical process issues, artifacts, artifact solution spaces, and systemic analyses. Socio-technical systems strategies were applied to computerized seamless V-bed knitwear design and manufacturing process to improve the integration or inclusion of high-fashion knitwear designers in the process through the balance of job enlargement and job enrichment. This ultimately affects the whole workflow and produces the new integrated high-fashion knitwear development process using computerized seamless V-bed knitting technology.

One of the key reasons for adopting this socio-technical system-based approach in this research is that socio-technical system provides a well developed epistemological foundation for organizational change – the most likely research outcome. The links are obvious. Organizational development deals with the total of the systems relating to an organization — the organization as a whole, including its operations and its environment — or with a subsystem or systems — departments or work groups — in the context of the total system (McNamara, 2010). Parts of systems, for example, individuals, cliques, structures, norms, values, and products are not considered in isolation. The principle of interdependency, that is, that change in one part of a system affects the other parts, is fully recognized. Organizational development interventions also include the total culture and cultural processes of organizations and their associated environments. Pragmatically, this results in a focus also on groups because the behavior of individuals in organizations and groups is shaped by or a product of group influences over and above the behaviors due to an individual's personality (Forsyth, n.d.). All of these issues, however, are tightly linked in knitwear design to the physical garment itself, or rather, the production of the design information that fully describes the material, stitch pattern, garment shape, and how it is manufactured. This in turn brings the focus to the garment development process.

Key elements of garment development

In knitwear design and manufacture, there are two key reference points in garment development in both tradition and computerized seamless V-bed knitting systems: the *design specifications sheet* and the garment *1st sample*. The *design specifications sheet* as its name implies specifies everything about the design of a garment. The *1st sample* of a knitted garment has a complementary role in that it provides physical evidence of all aspects of the design and that the design can be knitted using the instructions in the design specification sheet.

The *design specifications sheet* and *1st sample* are crucial parts of the knitwear design and manufacturing process. The *design specifications sheet* is the document that a fashion knitwear designer creates to communicate with anyone involved in the sample production and main manufacture process of a garment. The attribute of the garment design as merchandise depends on how the knitwear designer effectively conveys her/his ideas by means of the *design specifications sheet*. The *design specifications sheet* contains the design details, including fabrics, trims, and special treatments (Stecker, 1996, p. 95). It also has a secondary role as a working document, a design rationale (Keiser & Garner, 2008, p. 304) record. The designer and others involved in the sample and main production makes notes on it to record design revisions and manufacturing details.

In the traditional, non-computerized knitwear design process, the *design specifications sheet* contains technical fashion drawings, known as 'flats' in the industry (Abling, 1988, p. 313). The 'flats' visually communicate design information and details to pattern makers (or pattern cutters), who draft the shapes and sizes of garments' pieces. They also provide garment construction detail to the sample and production make-up staff. To draw 'flats' does not need artistic skills; however, it requires accuracy in proportioning sizes. The flats also appear on designer storyboards and costing sheets, and the *design specifications sheet*s.

In computerized seamless V-bed knitwear systems, the role of the *design specifications sheet* is addressed by a combination of paper documentation, the knit data files and the *1st sample* of the fabric or garment.

In knitwear, *1st sample* is the first successfully produced fabric or garment that is produced using the knit data and the correct yarns. It has a similar to, but has a more developed role than, the first garment sample known as 'toile' in woven wear fashion design. In conventional fashion design in woven fabrics, the toile garment sample is cut very often in a cheap fabric such as 'calico' following the first paper/cardboard pattern, and is then made up by the sample mechanist (Stecker, 1996, p. 94).

In computerized seamless V-bed knitwear design, prior to the *1st sample*, the 'knit-ability' of the design is tested by knitting the new design with acrylic yarn using the knit data. Acrylic yarn is used because it is highly tolerant of problems with the knit programming. These acrylic fabrics and garments are often called 'prototypes'. Using these acrylic yarn prototypes as test pieces, the *design specifications sheet* and knit data files are revised until the garment will knit using the intended yarns. To recap, the *1st sample* is the example of the practical real outcome of the *design specifications sheet* in the correct yarn. It is only at this point that the knitwear designer can have full confidence that the knit data will produce exactly the fabric or garment that they intended.

Comparison of garment development processes between knitwear and woven wear design

To develop the *1st sample* of knitwear, the knitwear designer usually goes through the same garment design development process as a fashion designer – but twice. The knitwear designer has to follow two design processes: one process is needed for creating the knitted fabrics used in the garment and the other for designing the garment shapes (Figure 41). To design knitwear means considering the different steps in succession, even in the design process (Yang, 2007, p. 9). As a result, knitwear designers sometimes need to prepare two different *design specifications sheet*s for a single garment, one for the knitted fabrics and the other for the garment shapes. Figure 41 shows a typical simplified garment development process for knitwear design.

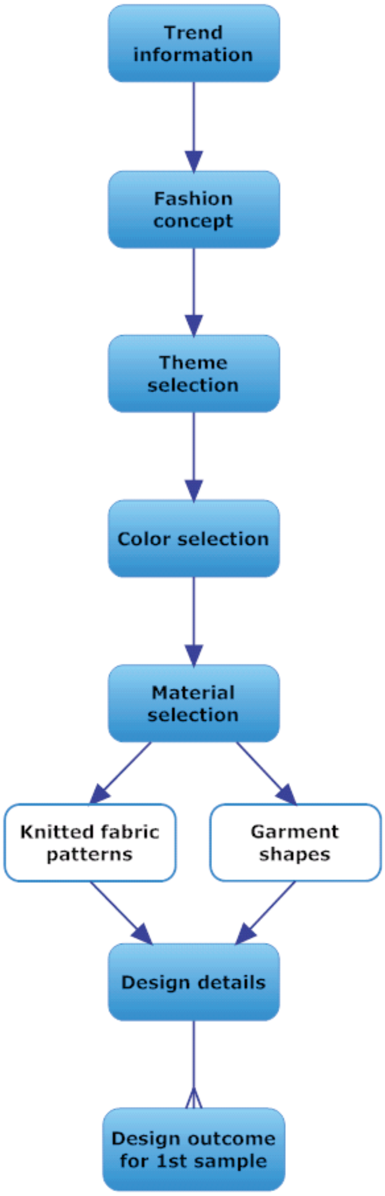


Figure 41: Typical simplified knitwear design process

In the knitwear industry, which at the moment predominately uses knitting machines that are not computerized seamless V-bed knitting systems, the details of the ways these two procedures are undertaken, the design processes used for knitted fabrics and garment shapes, differ from company to company. In some cases, the two different processes extend well beyond the design phase and in many cases extend all the way to the point of prototyping in final production. This is because small changes in knit characteristics or structure can change garment shape and drape. A small number of these issues may appear in final production and require, for instance, the use of fabric prototypes to check stitch pattern(s), garment prototypes to check garment shapes, and the use of both prototypes combined because different stitch patterns create different garment shapes (Gioello, 1982; Hatch, 1993; Lee, 2003; Newton, 1992; Pizzuto et al., 1980; Spencer & Knovel (Firm), 2001).

In contrast, to make *1st sample* using computerized seamless V-bed knitting systems, the knitwear designer works on the sample *design specifications sheet* for fabric texture and garment shapes in one sequential process. Once a *1st sample* is correctly produced using knit data, a combination of knit data code for fabric stitch pattern/s and a garment shape, then the knitting machines will replicate this.

Conventional computerized V-bed knitwear development processes

In this section, there are descriptions of two different garment development processes for knitwear design. The first describes the conventional role and tasks of the knitwear designer using computerized *non-seamless* V-bed knitting and the second describes the role and tasks of the knitwear designer involved in conventional computerized *seamless* V-bed knitting.

As discussed earlier, the design process for knitwear is larger and more complex than for woven fashion design because it has to address fabric design as well as garment design. Firstly, the colors, stitch patterns that form the texture, and the garment shape, are created simultaneously (Figure 41). Unlike woven wear fashion design, best quality outcomes in knitwear design have been limited by the highly interlinked nature of the roles of the three professionals involved: the knitwear designer, the knitting machine technician and the knitting machine operator. As a result, successful outcomes have depended on intensive collaboration between the three when preparing the *design specifications sheet* for *1st sample* garment. For a variety of reasons, this collaboration has been problematic (Eckert, 2001; Eckert & Stacey, 1994; Eckert et al., 1999).

In the current non-seamless approach to high-fashion knitwear design, the knitwear designer is actively involved up to the point of creation of the *design specifications sheet*, a paper document presented in written and graphic formats, and its handover via the production manager to both the pattern maker and the knitting machine technician. At this stage, however, no garment has been knitted, and it is unclear that the garment can be knitted. Typically, the knitwear designer makes several copies of the *design specifications sheet*s and passes them to the production manager. The production manager (the title varies from company to company) is typically a person who is at the top among the production make-up staff. In some knitwear companies either the pattern maker or the knitting machine technician might have the role of this position. Figure 42 illustrates the main elements of this process and their sequence.

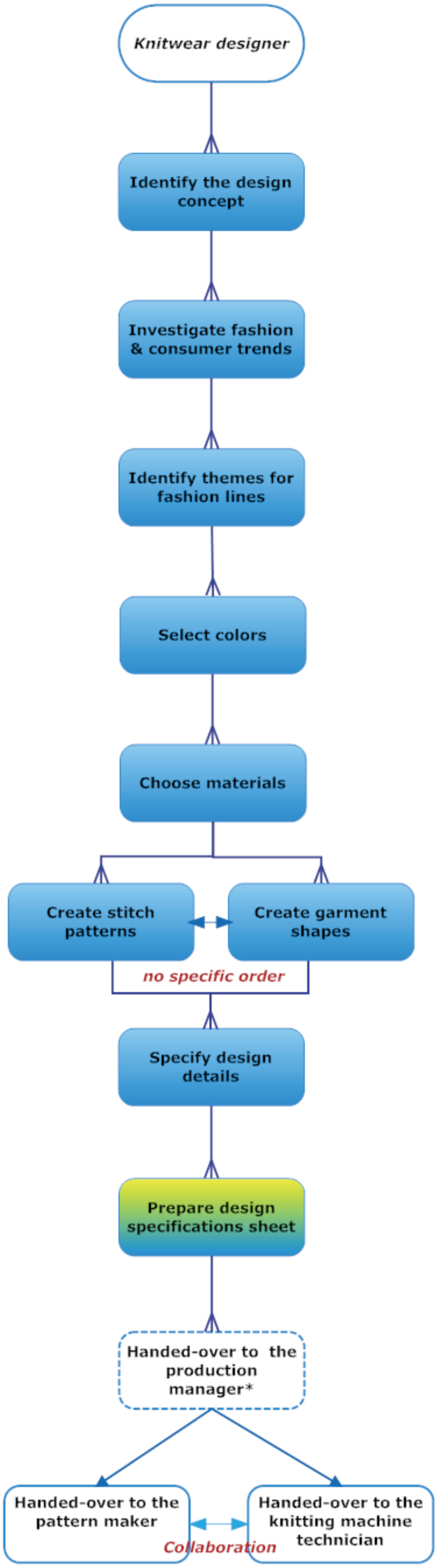


Figure 42: Knitwear designers' activities up to the handover of the *design specifications sheet* in a conventional computerized knitwear design and manufacturing process

The development process for knitted fashion garments must result in a sample garment in the same manner as any other fashion garment development process. As explained earlier, knitwear design has additional complications over conventional woven fashion design procedure because the process has to include the design for the knitted fabric and also the process to create that fabric.

In the case of WholeGarment® knitting, a computer program is used to create the knitting data to produce the *1st sample* garment. Conventionally, this process is split between two people: knitwear designer and knitting machine technician via an 'over the wall' or 'waterfall' development process similar to the one illustrated above in Figure 42 in which the knitwear designer hands over a *design specifications sheet* to the knitting machine technician. The problem is that in the creation of the *1st sample*, the two activities are not independent. Many apparently 'knittable' fabrics are actually not, and the full possibilities of creative potential of the WholeGarment® knitting machine is neither fully explored nor represented in the software that is intended to be the sole point of access of the knitwear designer. The result is that it is necessary for high-fashion knitwear design with the existing workflow process for there to be high levels of collaboration between the high-fashion knitwear designer and the knitting machine technician. This is however rarely possible. Blocking it are several factors, as described earlier, in terms of the differing cultures, workflows, design processes and work pressures underlying both roles. In addition, there are insufficient knitting machine technicians; they are expensive to employ, their training and culture acts against them being collaborative partners in the creative aspects of knitwear design, and the weight of focus of their work is towards maximizing production; and the management of the knitters – that is, the knitting machine operators.

The complexity of interdependence between a high-fashion knitwear designer and a knitting machine technician in the development of a new high-fashion garment is illustrated in Figure 43, which shows a typical computerized V-bed knitwear development process to the point of producing the *1st sample*.

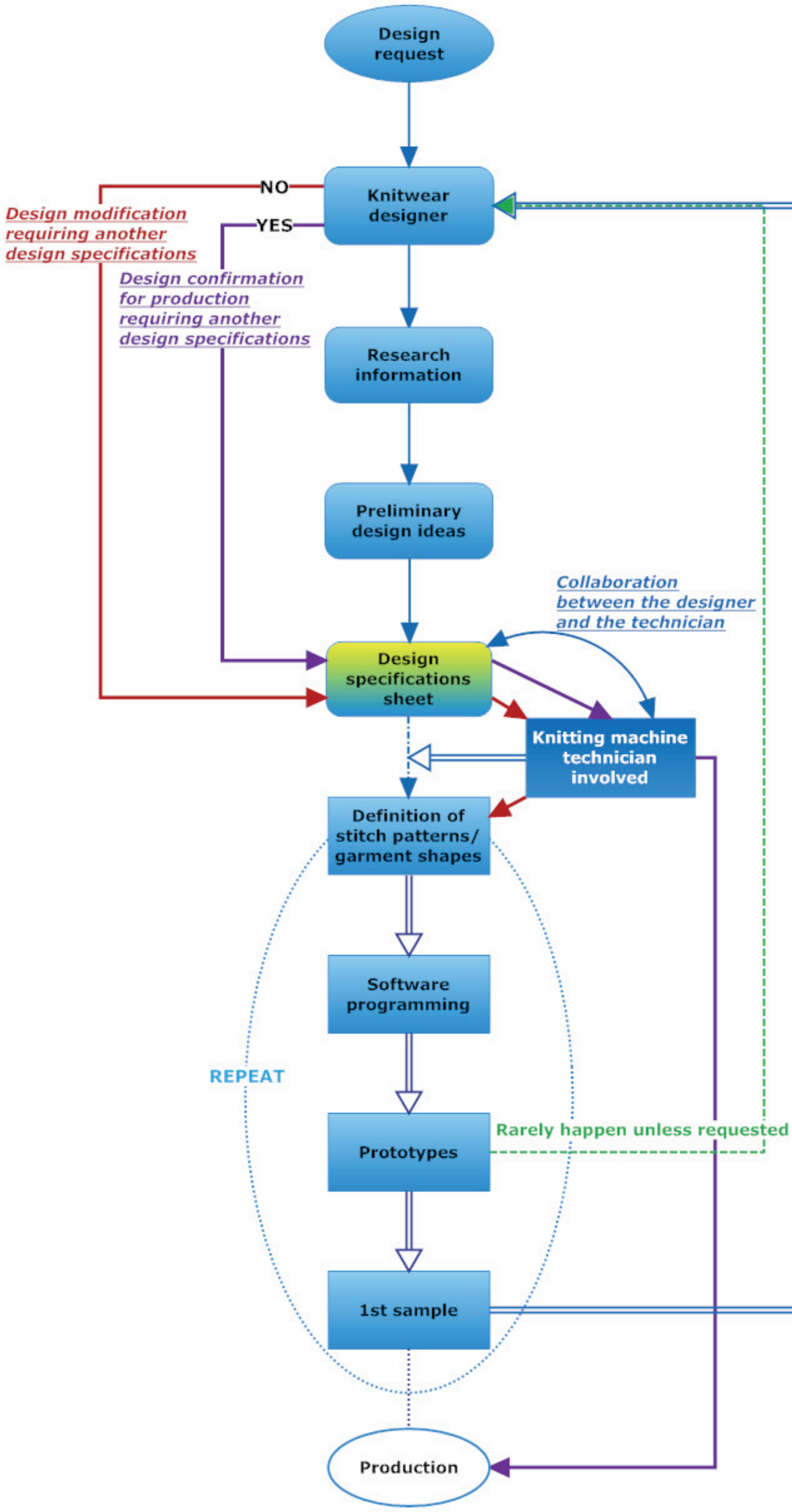


Figure 43: Conventional workflow of computerized V-bed knitwear design and production process to the creation of *1st sample*

The core sequence of the design or garment development steps is hierarchical and never changes. The minor details of the sequence, however, vary under different circumstances and there is no specific order among the designer's design activities. In experiments involving these processes, the knitwear designer can start with any stage that suits her circumstances at the time, as long as she handles it by herself. The hierarchical steps are embedded in the garment development process, as soon as the *design specifications sheet* is ready to go (Figure 43).

In the above problematic computerized V-bed knitwear design development process, the problems can be seen as a 'communication bottleneck' that compromises this essential collaboration (Eckert, 2001). Conventionally, after the fashion knitwear designer has completed the functional steps in Figure 43, they then hand over the *design specifications sheet* to the knitting machine technician who decides what type of knitting machine to use and programs the knitting machine to produce the first prototype.

As explained earlier, the 'prototypes' are knitted using the same knit data as the *1st sample*, but with relatively cheap acrylic yarn, which is more forgiving to knit. This is done to check the feasibility of the design on the knitting machine and the knitted quality. The *1st sample* is produced using the correct yarns. Although the later stages should require substantial input from the fashion knitwear designer, typically the fashion knitwear designer is excluded, and this work is done wholly by the knitting machine technician with the result that the *1st sample* differs substantially from what the designer intended. The knitting machine technician receives the *design specifications sheet* and uses the apparel workstation system to program the knit data and may operate the computerized knitting machine by herself/himself or have a knitting machine operator run it. When the programming is functioning satisfactorily, then, *1st sample* garment is knitted using the correct yarns.

The above workflow model applies to any type of *1st sample* production, which may be fully-cut, garment length knitting, fully-fashioned, integral garment knitting (conventional computerized non-seamless V-bed knitwear production), and WholeGarment® knitting (conventional computerized seamless V-bed knitwear production). Note that four steps need to be repeated for the creation of knitted fabric to check texture of stitch patterns and of garment shapes. It is only at this point, that the prototype can be fully checked to give confidence that what will be knitted is likely to be what was designed. The steps in the development process may have a slightly different order from company to company and some steps added or deleted depending on the types of garment a company is manufacturing, and its marketing position.

This need for, and lack of, collaboration between a knitwear designer and a knitting machine technician in the creation of *1st sample* in conventional computerized V-bed knitwear design development contrast socio-technical system with most other forms of fashion knitwear design in which designers simply make *1st sample* themselves by hand via a combination of draping and flat patternmaking using patterns made from paper or cardboard (Stecker, 1996).

The knitting machine technician's workflow to creation of *1st sample*

In the conventional garment development process of computerized V-bed knitwear design, the knitting machine technician follows a specific workflow after they receive the *design specifications sheet*. The knitting machine technician pays close attention to all the details on the *design specifications sheet* to understand the designer's intention. Secondly, he checks the technical details regarding production are within the specifications of the job. Third, he develops a strategy to complete the knitting production task as cheaply as possible.

In the typical 'over the wall' computerized V-bed knitwear development approach, the knitting machine technician's workflow process illustrated in Figure 44 follows directly on from the workflow process for the knitwear designer and knitting machine technician shown in Figure 43 above. After deciding which knitting machine is to be used, the knitting machine technician prepares a technical specifications sheet for herself/himself and the knitting machine operator, if the knitting machine technician chooses delegate the actual knitting. Both paths are shown in Figure 44.

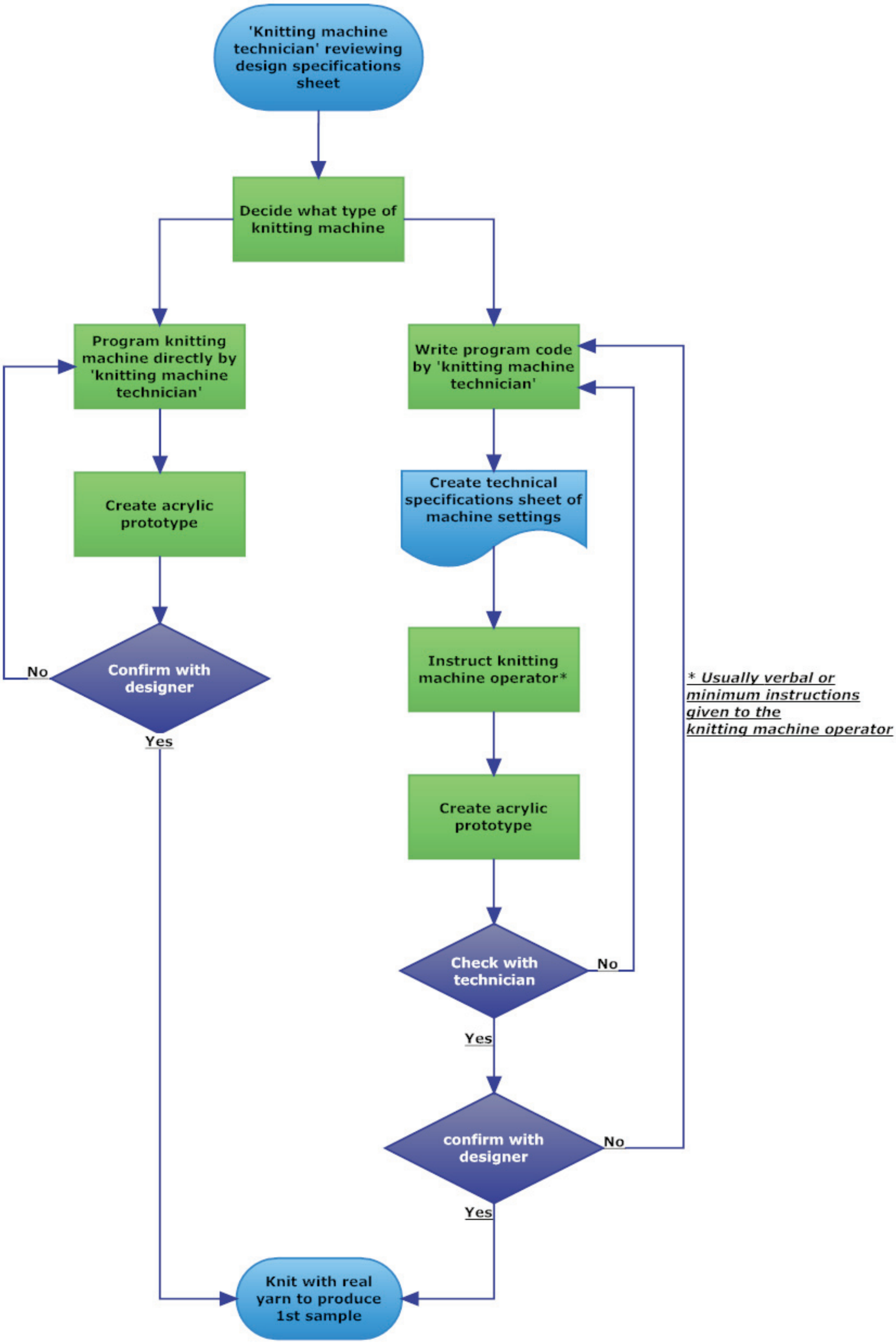


Figure 44: Knitting machine technician's activities after *design specifications sheets* hand-over

The knitting workflow

Other aspects of the complexity of the conventional computerized V-bed knitwear development process to the point of *1st sample* production are revealed by examination of the technicalities of the knitting workflow itself which commonly involves the activities of knitwear designer, knitting machine technician, and knitting machine operator as described above, with the knitting machine technician sometimes undertaking the role of the knitting machine operator. The workflow with the detail of the knitting process is illustrated in Figure 45.

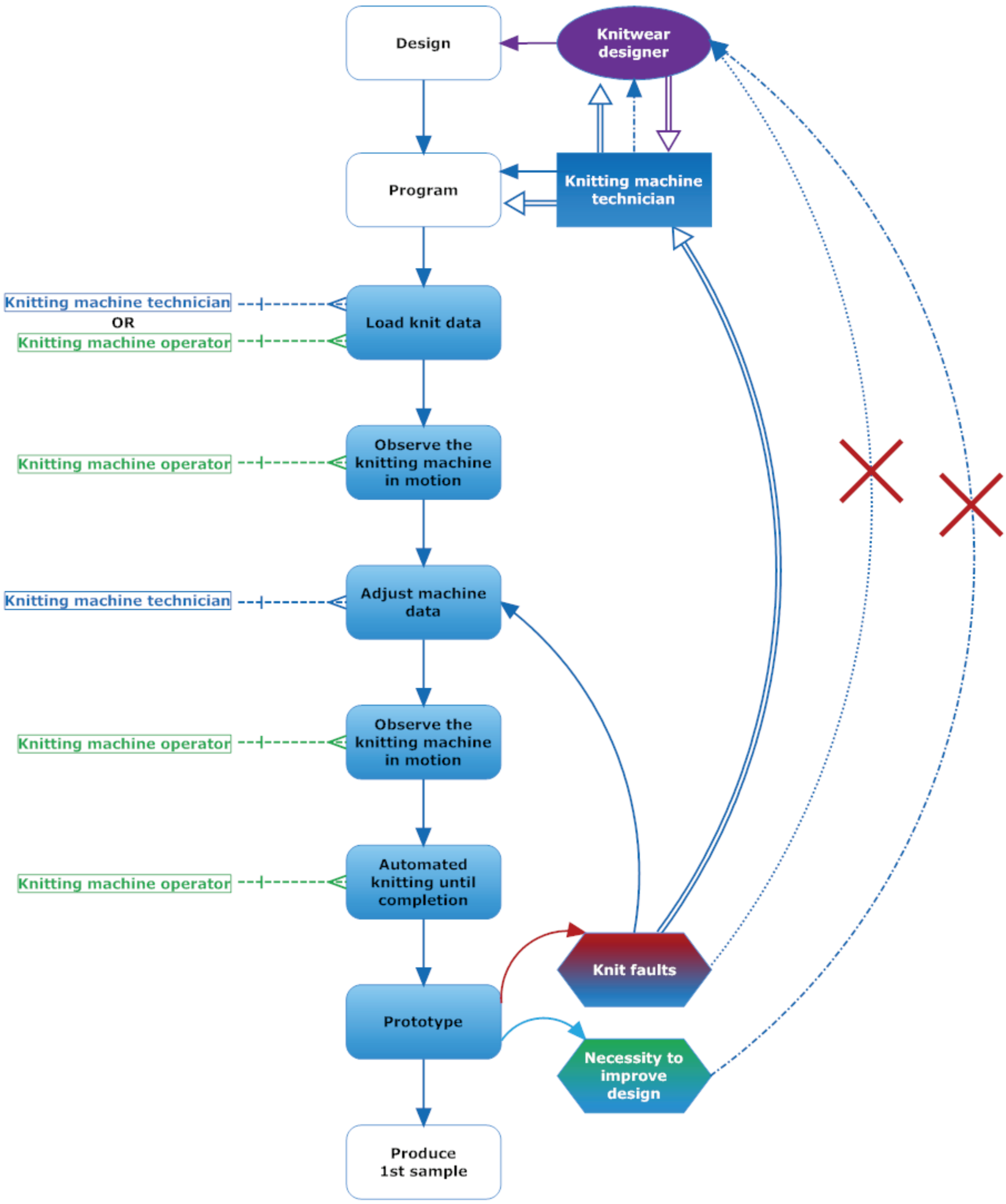


Figure 45: Conventional computerized V-bed knitwear prototyping process showing expanded detail of the knitting process to *1st sample* and feedback loops

The knitwear designer, the knitting machine technician, and the knitting machine operator each has a role to play in the garment development workflow. The diagram shows two obviously beneficial workflow feedback loops between the knitting machine operator and the knitwear designer. These do not exist in reality. There is no direct communication channel between the knitwear designer and the knitting machine operator. Instead, when there are faults with prototypes or the necessity to improve the design, the knitting machine technician deals with these first. The lack of a direct feedback communication channel to the knitwear designer may result in a significant loss of information that could alter a design and make it unusable. Furthermore, designs that might cause problems in production could be corrected at the early stages of *1st sample* development process.

Design improvement, especially for aesthetic reasons, is made after the completion of *1st sample* in most cases, unless it is accidentally spotted by the designer while being held on the knitting machine and they informally manage to convince the knitting machine technician to make the necessary changes. Usually, any knit faults are fixed by the knitting machine technician if the fault is within the boundary of the knitting machine technician's expertise. These often result in changes to the knitted fabric or the garment structure and appearance and the designer is not informed, On the contrary, when the knitwear design needs to go for serious modifications, it sometimes ends up as something totally different from what the designer intended. Anecdotally, knitwear designers hear technicians saying "they look all the same to me" about knitted garment designs.

The knitting machine operator's role

The knitting machine operator is the individual who physically operates the industrial knitting machines. The machines may be wholly manual, half-manual, automated or computerized. The knitting machine operator normally looks after a group of knitting machines. Their work responsibilities mean that they like to see all knitting machines under their care knitting productively as much of the time as possible. The knitting machine operator is usually given verbal instructions. Minimum written instructions are given. The knitting machine operator often avoids working on prototypes and *1st samples*. In part this is because it means that their time is taken away from managing productive knitting machines, in part it is because it involves a different way of working, and in part because it is slow. From the knitting machine operator's point of view, working on prototypes is worse than producing *1st samples*, because it requires frequent machine stops due to programming errors and faulty machine setting data. Even if a knitting machine operator wished to participate more in supporting the knitwear design process, it is mentally and physically difficult for them because knitting machine operators are managing many noisy knitting machines in a noisy and highly pressured environment. Further, knitting machine operators do not have the authority to adjust the knitting program independently of instructions from the knitting machine managers or technicians.

As described earlier, the knitwear designer is almost completely excluded from the design process and the primary responsibilities of the knitting machine technician and knitting machine operators lie elsewhere resulting in them being unable to pay much attention to what for them is an incidental and secondary aspect of their work.

CHAPTER 6: Research Methodology

This chapter describes the research methodology that underpins the choice of theoretical research perspectives, research methods for data collection and analysis used in this PhD research. The chapter describes in detail how the choice of data collection and analysis methods gather the appropriate data in a triangulated research approach that led to the research findings described in later chapters that resolved the research problem identified in Chapter 1.

In this PhD research, computerized high-fashion knitwear design and manufacture is viewed as a socio-technical system (STS). A socio-technical system comprises all aspects of a system both social and technological. It includes the human roles, influences, behaviors and socio-cultural consideration alongside the technology and technology processes, information flows, traditions of practice, educational processes, and business processes (Trist & Ontario Quality of Working Life, 1981). Taken together, the socio-technical system in focus in this research includes all dimensions of the computerized seamless V-bed knitwear process and fashion system in all its dimensions including the designers and other participants.

In this research, a participatory action research approach was applied that complements this focus of research as a socio-technical system. In this participatory action research approach, the researcher undertook several different roles across multiple real world fashion knitwear projects using this computerized knitwear socio-technical system. The details of these fashion projects and the development of knitted garment designs are described more fully elsewhere in this thesis.

The overall research problem this PhD addressed was to identify ways to improve the use of computerized seamless V-bed knitting technologies in the design and production of high-fashion knitted garments. It did this by gathering and analyzing information to answer three research questions (identified in earlier chapters):

- How much of the roles of the knitting machine technician and knitting machine operator can be undertaken by the knitwear designer to the point of 1st sample garment?

- What would be a more efficacious high-fashion knitwear design development process to the point of 1st sample with the knitwear designer undertaking more of the roles of the knitting machine technician and knitting machine operator?
- Can this new approach be taught?

The primary interest of the research was high-fashion knitwear design processes rather than routine retail mass-market knitwear design. There are important differences between high-fashion knitwear and routine knitwear in both design and manufacturing processes. High-fashion garment is usually involves more extreme garment shapes and fabrics, made with extreme attention to details and finishing, and also, look and fit that take priority over the cost of materials and the time it takes to make. High-fashion knitwear design requires going beyond what is available with the routine use of the computerized seamless V-bed knitting system. The details of the overall research problem as it relates to high-fashion knitwear design were revealed by the conflicts between constituents and stakeholders in the design and manufacture process and the needs, processes, skills and cultures of knitwear designers, knitting machine technicians and knitting machine operators and is especially visible in relation to high-fashion knitwear.

In this PhD, there existed an unusual research methods opportunity resulting from the researcher's pre-existing skills across high-fashion knitwear design and manufacture. The researcher has substantial experience as a high-fashion knitwear, textile designer, and manager of a computerized knitting business. In addition, by undertaking training at Shima Seiki in programming and operating a WholeGarment® computerized seamless V-bed knitting system, the researcher acquired the skills of knitting machine technicians and operators that are directly relevant to high-fashion knitwear designers creating prototypes and samples of knitwear. Taken together, this offered potential for a participatory action research approach in which a research as an individual fashion knitwear designer could undertake real world organizational experiments involving all three of knitwear designer, knitting machine technician and knitting machine operator.

The participatory action research was undertaken through multiple practical investigations involving real world knitwear fashion projects. These knitwear projects (each an example of knitwear design and manufacture as a socio-technical system project) provided empirical insights and means of trialing and testing those insights via the involvement of the researcher as participant-observer. That is, the researcher acted as participant-observer in the socio-technical system of computerized seamless V-bed knitwear design and manufacture whilst investigating and developing improvements that address the problems and tensions between the different roles of practitioners in computerized seamless V-bed knitwear in order to explore the potential to radically change these roles to improve the computerized seamless V-bed high-fashion knitwear design and manufacture process.

Research into computerized knitwear as an socio-technical system

The main focus of this research into improving design and production of high-fashion knitwear as a socio-technical system using the Shima Seiki knitting system as an instance of computerized seamless V-bed knitwear design and manufacture is across five areas:

- **Designing** using the apparel design workstation;
- **Programming** the knitting machine;
- **Operating** the knitting machine;
- **Educating** novice fashion design students in being able to use the new approach for the Shima Seiki knitting system: and
- **Changes in industry process** of the knitwear design industry.

As described earlier, preliminary research reported in Chapters 2 to 6 indicated opportunities for improving the knitwear design and manufacture process to the point of *1st sample* by changing the relative roles, tasks and education of the three main practitioners involved in the computerized knitwear process:

- High-fashion designers;
- Knitting machine technicians; and
- Knitting machine operators.

The research used a practical experimental approach in which the researcher, as a high-fashion designer, undertook all three of the above roles whilst engaging in real world fashion design projects. This was done to investigate the possibility for high-fashion knitwear designers in general to undertake the knitting machine technician and operator roles in garment prototyping up to *1st sample* to improve the design and manufacture process of the design outcome.

Using the same theoretical perspective, the international high-fashion knitwear industry, can be also regarded in this PhD as a socio-technical system (in a similar manner to the computerized seamless V-bed knitwear system). As a socio-technical system, the international high-fashion knitwear industry is an interlinked, system comprising a mixture of people, technology, their environment, and their organizational processes.

To summarize, a combination of factors places the research at the nexus of participatory action research and socio-technical system development with the researcher participating as a researcher and also as a participant in multiple practical roles in the socio-technical system. The research used a participatory action research perspective, in which the researcher was both participant-observer and practitioner. Acting in their capacity as a high-fashion designer, the researcher created designs and operated all aspects of the computerized seamless V-bed knitting with Shima Seiki knitting machine. This included all those tasks and processes normally the dedicated responsibilities of knitting machine technicians and operators. In parallel, this approach resulted in conceptually contiguous socio-technical system that provided the basis for the researcher to project the research analyses and findings more broadly into the context. That is, the findings of the research provide the basis for proposing a new more effective process of design and manufacture in the international high-fashion knitwear industry.

Socio-Technical Systems

At a fundamental level, the purpose of this research is one of improving a work process in a Socio-Technical System including people and technology. This aligns exactly with the role of socio-technical systems described in the socio-technical theory and socio-technical systems analysis developed by Trist and others (Cartelli, 2007; Frey, 2009; Tavistock institute of human, Trist, & Murray, 1993; Whitworth, 2006).

The notion of the socio-technical system originated in the fifties (Emery & Trist, 1960). Socio-technical systems analysis was developed to address the theoretical and practical problems of designing the increasingly complex working conditions in industry. Trist's organizational paradigms used the socio-technical system concept to establish a new way of looking at and analyzing industry organizational and working practices (Trist & Ontario Quality of Working Life, 1981, p. 42). In its time, this represented a milestone that changed the boundaries of theory and research into industry and professional practice environments. Trist and other's concepts of the socio-technical system emphasized the mutual interrelationship between humans and machines and promoted the idea of viewing work as 'total work systems'. The approach considers both the technical and the social conditions of work in such a way that efficiency and humanity benefit are not mutually exclusive. Trist's insights remain applicable to contemporary industrial context such as computerized seamless V-bed knitting and the international high-fashion knitwear industries.

The concept of a socio-technical system is a systems-based extension of socio-technical theory in which a system that includes social and technical arrangements is the whole as opposed to the multiplicity of individual elements and disparate relationships between them. A system includes the relationships between its parts composed in a purposeful way (Ropohl, 1999, p. 2 refering to writings of Aristotle and Lambert; Trist & Ontario Quality of Working Life, 1981)).

In organizational development, socio-technical systems analysis when used as an approach to complex organizational work design, identifies transactions between people and technology within a larger organizational context. These transactions describe interactions that occur within a socio-technical system (and its sub-systems) and between the socio-technical system and the wider context and dynamics of the environment (in this case, between the socio-technical system of the computerized seamless V-bed knitting system and the socio-technical system of the international high-fashion knitwear industry context and the parallel high-fashion retail context). The term, *transaction*, also refers to the interaction between society's complex infrastructures and human behavior. In this sense, society itself, and most of its substructures, including culture can be viewed as complex socio-technical systems with the transactions within them.

Initially, in the early years of socio-technical system analysis, technology was considered to be more important, and regarded as the independent, more or less autonomous, variable. The mental and social conditions of human work were assumed to be secondary to be modified to follow the given technical structures and technology (Ropohl, 1999, p.1). Almost immediately, the social and subjective aspects of socio-technical systems became included on a similar footing to technology. In part, this paralleled approaches to analysis that structure socio-technical systems analysis in terms of a system of systems approach addressing the *micro*, *meso* and *macro* systems analysis of socio-technical systems.

Micro, Meso, and Macro approach

This research can be conceived in socio-technical system terms in the manner of the triplet of micro−, meso−, and macro−level systems analysis representing, 'the individual', 'the organization', and 'the society' (see, for example, Bronfenbrenner, 1979; Ropohl, 1999). The three engagement areas of the research described earlier were regarded in terms of this micro, meso, and macro socio-technical systems model (Figure 46):

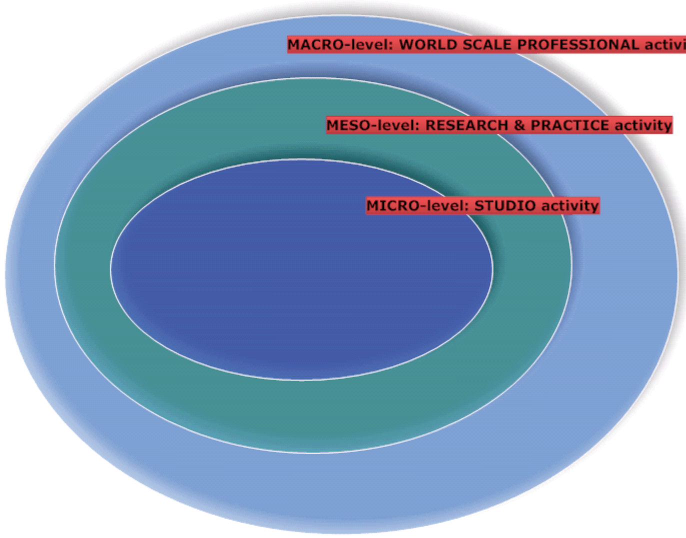


Figure 46: The researcher's three level world of socio-technical system

- *Micro systems analysis*: studio activity is regarded as the socio-technical system of the researcher, computerized seamless V-bed knitting system, and participants in design and production of real world garments;
- *Meso systems analysis*: research and practice activity involving the stakeholder organizations, for example, Curtin University of Technology and DAFWA, and the studio activity and research participants; and
- *Macro systems analysis*: world scale professional activity involving computerized high-fashion knitwear industry and studios, and international research and practice constituents.

Paradigm change via socio-technical system analysis

The theory contained in Trist's Socio-Technical Systems approach (Trist & Ontario Quality of Working Life, 1981, p. 42) provided this research a coherent basis for investigating improvements to the computerized knitwear development process using the Shima Seiki WholeGarment® computerized seamless V-bed knitting system and provided the basis for identifying characteristics of the new socio-technical systems-based paradigm the research explored. Table 7 compares the key features of a new socio-technical system view of computerized seamless V-bed high-fashion knitwear design using Trist's organizational paradigm in comparison with the conventional paradigm of computerized knitwear design and manufacture processes.

Table 7: New vs. old paradigms for high-fashion computerized knitwear design and manufacture process. Following example of (Trist & Ontario Quality of Working Life, 1981, p. 42)

New paradigm	Old paradigm
Joint optimization	The technical imperative
Man as complementary to the machine	Man as an extension of the machine
Man as a resource to be developed	Man as an expendable spare part
Optimum task grouping, multiple broad skills	Maximum task breakdown, simple narrow skills
Internal controls (Self-regulating subsystems)	External controls (supervisors, specialist staffs, procedures)
Flat organization chart, participatory style	Tall organization chart, autocratic style
Collaboration, collegiality	Competition, gamesmanship
Members' and society's purposes also	Organization's purposes only
Commitment	Alienation
innovation	Low risk-taking

The factors in the left column of the Table 7 defined the philosophical issues to be addressed. Particular issues from Trist's paradigmic analysis particularly relevant to this research were his idea of: 'man as complementary to the machine', 'multiple broad skills' 'internal controls' and 'innovation'. These provided useful direction for the explorations undertaken in this research.

Work process analysis

Central to classic socio-technical systems analysis is the study of workflows (Blumberg & Gerwin, 1984; Clegg, 1984). This suggested that a key aspect of improving high-fashion computerized knitwear design and manufacture was to carefully analyze the existing and proposed work processes of the three main groups of professionals involved in design and manufacture using computerized seamless V-bed knitwear systems.

The workflow processes are more complex for knitwear design and manufacture compared to woven garment design and manufacture in spite of the fact that component shapes of knitted garments are typically simpler than those made of woven fabrics (Brackenbury, 1992, p. 39). Knitwear designers have to undertake two extra major processes compared to woven garment designers. Knitwear designers have to undertake the process of creating the design of the fabric, i.e. the design and programming of the stitch pattern design of the knitted fabric, and they need to create and manage the process for creating that fabric. In woven garment design, these two processes are undertaken in a separate discipline, Textile design.

In the conventional approach to computerized seamless V-bed knitwear design, is a different division of labor and this presents the problems that are addressed in this research. In conventional computerized knitwear design and manufacture process, the design process is problematically split between two roles; the knitwear designer and the knitting machine technician. The design process is commonly undertaken via a traditional 'over the wall' or 'waterfall' design sequence in which the knitwear designer hands over to the knitting machine technician a written design specifications sheet describing the design in words. The knitting machine technician then uses this design specifications sheet as the basis for them to program the knitting software to create the *1st sample* garment and then, later, to reprogram the *1st sample* design for mass production. Commonly, the fashion designer's intent and creative garment inspiration is lost in this 'over the wall' design process.

A further problem is the two activities of 'creating the design specifications sheet' and 'programming the *1st sample*' are highly interdependent. They overlap in many ways and have recursive loops. Problems with conflicts in the design workflow can be seen most clearly in the activities involving design and programming of the *1st sample*. To resolve these interdependence problems in the design process requires high levels of collaboration between the high-fashion knitwear designer and the knitting machine technician. The segregation of the tasks up to *1st sample*, the waterfall design process, and handover workflow approach result in failure of the garment design process because they block collaboration between knitwear designer and knitting machine technician such that the activities of the necessary collaborative feedback loops are not undertaken. Other factors also contributing to blocking the necessary collaboration are the differing education backgrounds, work cultures and work pressures underlying each of the roles. There are insufficient knitting machine technicians; they are expensive to employ; their training and culture acts against them being collaborative partners in the creative aspects of knitwear design; and the weight of focus of their work is towards maximizing production and the management of the knitters – i.e., the knitting machine operators.

Garment programming the *1st sample* can also inspire new designs. Many apparently 'knittable' fabrics or garments are not. The above failures of design process means the creative potential of the computerized seamless v-bed knitting machine is neither fully explored by the designer because they do not use it, nor is represented in the software intended to be the sole point of access of the knitwear designer because the technicians and programmers do not create the high-fashion designs.

This research proposed that addressing the above swathe of problems associated with failures of collaboration between by the high-fashion knitwear designer, knitting machine technician and knitting machine operator can be resolved by the knitwear designer undertaking all aspects of the knitting machine technician and knitting machine operator roles to the point of production of *1st sample* garment.

This alternative was explored in this research by modifying the knitwear design and manufacture workflow and developing a new design and prototyping workflow for high-fashion design using computerized seamless V-bed knitwear systems, in which high-fashion knitwear designers incorporate some of the technical roles of the knitting machine technician and knitting machine operator. The natural system boundary of this new design and garment prototyping workflow process is at the culmination of the creation of *1st sample* which is the first sample of the garment successfully made in the yarns that the final garment will be produced. Earlier versions are made in relatively cheap acrylic yarn to troubleshoot the development of the knitting machine code. Later samples after the *1st sample* will be used to optimize the knitting code. The *1st sample*, therefore, defines the point at which the fashion design is completed and tested as aligning with the fashion designer's creative intent. Through the design and manufacture of the *1st sample*, the knitwear designer verifies the proposed garment is knittable; that the knitting software produces the garment that is intended; that the yarn and fabric performance and garment shape are as intended.

In the new integrated design and manufacture process proposed as a result of the research undertaken in this PhD, the knitwear designer undertakes the knitwear design, programs the knitting machine, and operates it. As a result, the proposed new integrated design and manufacturing system to the production of *1st sample* and after is simpler and divides the workflow, tasks and roles between the knitwear designer and the knitting machine technician in a more efficient, effective and more sensible manner compared to the conventional computerized V-bed knitwear design and production process. In addition, the proposed new design process provides knitwear designers with an effective loop of learning and design improvement within their own workflow.

Epistemology: Action Research and Participatory Action Research (PAR)

The research used an insider action research perspective to investigate and improve the system of professional activities involved in the design and manufacture of computerized seamless V-bed knitwear. Participatory Action Research (McKernan, 1996) was chosen as the primary epistemological and methodological perspective. Using this approach, the researcher acted as 'participant-observer' in the design processes of real world design and manufacture of high-fashion knitwear products created and manufactured using computerized seamless V-bed knitting design and manufacturing technology.

Participatory Action Research as its name suggests socio-technical system is a style of Action Research (see, for example, Master 2000). Epistemologically, the broad support in this context for the use of the Action Research paradigm (see, for example, Dick, 2002; McNiff & Whitehead, 2006; Wadsworth, 1988) supports the use the participatory action research approach in this PhD research and the conceptualization of the computerized knitwear design and manufacturing process as a socio-technical system.

Masters (2000) classified action research into three perspectives that she regarded as similar in methodologies, but different by way of fundamental theory or appropriation and world views of the participants.:

- Technical/technical-collaborative/scientific-technical/positivist action research;

- Mutual-collaborative/practical-deliberative-interpretivist perspective on action research; and
- Enhancement approach/critical-emancipatory action research/critical science perspective on action research.

She simplified these to:

- Technical action research;
- Mutual – collaboration action research; and
- Participatory action research.

In the context of Participatory Action Research, Kurt Lewin, in the mid 1940s, described action research as "proceeding in a spiral of steps, each of which is composed of planning, action and the evaluation of the result of action" (Kemmis & McTaggart, 1988, p. 8). This construction of action research theory by Lewin made action research a method of acceptable inquiry (McKernan, 1996, p. 9). Lewin argued that in order to "understand and change certain social practices, social scientists have to include practitioners from the real social world in all phases of inquiry" (McKernan, 1996, p. 10).

All Action Research involves creating real-world situations to enable participants to engage together in cycles of action and critical reflection, sometimes known as the action-reflection cycle (McNiff & Whitehead, 2006, p. 9). The basic process has been elaborated in different ways in different schools of practice (Reason & McArdle, 2008, p. 4) and consequence, there are many versions of action research (see, for example, Cunningham, 1993; Dick, 2000; Kemmis & McTaggart, 1988; McNiff & Whitehead, 2006; Stringer, 2007; Walker & Haslett, 2002).

Other issues in Action Research are education and power. From an educator's perspective, McNiff and Whitehead (2006, p. 42) claim that the origins of action research lay in education:

> *In the 1930s and 1940s, through its use in the work of Lawrence Stenhouse and his idea of 'teacher as researcher'…*

Differences in Action Research approach can be viewed in terms of power issues (Grundy 1982, p. 363) depending whether the power resides with the researcher, individuals, or the group:

The differences in the relationship between the participants and the source and scope of the guiding 'idea' can be traced to a question of power. In technical action research it is the 'idea' which is the source of power for action and since the 'idea' often resides with the facilitator, it is the facilitator who controls power in the project. In practical action research power is shared between a group of equal participants, but the emphasis is upon individual power for action. Power in emancipatory action research resides wholly within the group, not with the facilitator and not with the individuals within the group. It is often the change in power relationships within a group that causes a shift from one mode to another.

This research uses participatory action research with the researcher acting in all roles. Hence, the power considerations are not significant.

The Participatory action approach is useful and relevant because improving the behavior, functioning and outcomes of socio-technical systems such as computerized seamless V-bed knitwear design and manufacturing systems involves trialing and evaluating changes in a complex interplay between the activities and learning of the researcher/participant practitioner activities; the roles, interactions and interdependencies with immediate co-workers/peers, and the individual’s role in the wider organizations (see, for example, Wadsworth, 1988)

The use of a participatory action research approach in this research enabled attention to be paid simultaneously to three different perspectives of first−, to second−, to third−person research practice (Reason and McArdle (2008, p. 7). Lang (2009):

- Research on the practitioner’s own actions, aimed primarily at personal change of skill, knowledge and process (in this case redefining the skills of the fashion designer);
- Research on the roles, workflows and interactions of the group/team [in this case, including the roles of knitwear designer, knitting machine technician and knitting machine operator], aimed primarily at improving the group processes and outcomes [in this case, combining the roles of technician and knitting machine operator within the knitwear designer’s role]; and
- ‘Scholarly’ research aimed primarily at theoretical generalization and/or large scale change [developing an improved process model of computerized knitwear design and manufacture that integrates the above three roles].

In this PhD, the application of the participatory action research approach matches well with the above and with this research situation in which the aim is to transform working processes in a socio-technical system that includes a community of practice (computerized knitwear design and manufacture) in which the researcher, herself, is engaged as researcher and practitioner.

Participatory Action Research was also an appropriate basis for this research because it gathered the information necessary to address the research questions, whilst enabling the researcher as professional knitwear designer to be a participant in the research context to modify and improve the high-fashion knitwear design processes and practices during the course of each knitwear project. The knitwear projects included production of a variety of knitted fabrics and garments mainly for fashion shows to display the benefits for Western Australian wool (Farren et al., 2006). Garments and fabrics were made also as part of Curtin University fashion student's education and public design shows (Farren & Clarke, 2009).

The research was extended and triangulated by including the researcher's reflections and practice notes from three periods of residential technician training at Shima Seiki (see Appendix 4) and several courses of practical teaching for fashion design students in the new techniques of design and manufacture of computerized knitting developed in this research (see Project 4 and 8 in Appendix 1).

Four Roles: Researcher, Participant-Observer, High-fashion Knitwear Design Practitioner, and Educator

Using the Participatory Action Research paradigm involved the researcher undertaking multiple roles in the research that overlapped in different ways at different times:

- **Researcher**: responsible for management of the research; gathering and analyzing the data; identifying the findings and writing up the research in this thesis
- **Participant-observer**: in this the research participates authentically in several real world computerized knitwear design and manufacture projects whilst observing and gathering data about the processes. As participant-observer, the researcher undertook multiple and different practitioner and professional roles.
- **Practitioner**: the researcher as participant-observer simultaneously undertook the roles of knitwear designer, knitting machine technician and knitting machine

operator (usually distinct non-overlapping professional practices)across a range of commissioned projects; and

- **Educator**: the researcher as participant-observer undertook the role of tertiary education lecturer/tutor creating and trialing new fashion education programs and curricula involving the new knitwear design and manufacturing approach.

The researcher was able to address the complexity of the participant-observer role because of the researcher's prior skills and experience as a high-fashion knitwear and textile designer, and manager of a computerized knitting business with 75 staff[1]. In this research, the researcher was able to undertake the knitting machine technician and knitting machine operator roles in addition to the knitwear designer role through undertaking three periods of specialized residential training at Shima Seiki in Japan in programming and operating WholeGarment® knitting machines.

Components of Participatory Action Research in this project

Data gathering and analysis using the participatory action research paradigm used in this PhD comprised:

- Data collection and analysis of detailed records of design and manufacturing and related activities undertaken in eight real world design and manufacture projects involving the creation and manufacture of 531 different fabric and garment designs
- Data collection and analysis of the researcher/participant's subjective 'reflections' undertaking the fashion design projects and activities, including the identification of 'critical incidents';
- Mapping of the processes of knitwear design and manufacture from the point view of high-fashion knitwear designers, knitting machine technicians and knitting machine operators (Yang & Love, 2008).;
- Detailed analysis of knit data files for all the knitted fabric and garment samples produced during the research;
- Reflections on teaching sessions with university fashion design students to identify critical incidents that offers insights into teaching fashion students to develop knitwear designs using the Shima Seiki knitting system for public exhibition; and

[1] Design, production, and administration staff only, numbers of sales staff varied time to time.

- Analysis of moment to moment recording of events and critical incidents in the researcher's diaries and notes detailing the researcher's experiences in undertaking three sessions of residential training in Japan with Shima Seiki to learn to program the Shima Seiki WholeGarment® knitting machine using the Shima Seiki SDS-ONE® software system.

Data collection and analysis

In this research, multiple elements of data were drawn from the Shima Seki SDS-ONE® software and knitting software code and data files, from operation of the knitting machine, from using the software to design garments, and from teaching students. This multi-point holistic approach to data collection was undertaken to gather a rich understanding of design processes, design activities relating to projects, and education procedures. The specific details of the data collection approaches and data analysis procedures are documented in Appendix 2 and 3.

Data were collected from fourteen (14) different specific sources:

- Reflections of researcher as participant practitioner;
- Electronic mails (Emails) of stakeholders, clients, managers, designers, suppliers, trainers, students;
- Critical incident emails;
- Knit data files from Shima Seiki knitting system;
- *KnitPaint* design folder structure: (CAD) folders;
- Samples of produced fabrics and garments;
- Work diaries produced by the researcher as practitioner;
- Knitwear design specifications sheets;
- Knitted garment size specifications files and printouts of the size specifications files;
- Electronic images of fabrics and garments in studio and exhibition presentations;
- Class notes used for teaching Fashion Design students to design and manufacture garments using the Shima Seiki knitting system;
- Training notes from the researcher's training at Shima Seiki in Japan;
- Training data files developed by the researcher as practitioner while training at Shima Seiki in Japan; and
- PowerPoint presentation files used for teaching the students to design and manufacture garments using the Shima Seiki knitting system.

Reflections of the researcher/participant-observer as practitioner

‘Reflection’ is the active process of witnessing and examining one’s own experiences to explore them in greater depth (Amulya, n.d.; Goethals, Howard, & Sanders, 2004). Struggles, dilemma, uncertainty, and breakthroughs are kinds of experiences that create particularly powerful opportunities for learning through reflection (Amulya, n.d., p. 1). The knitting projects in this project in this PhD presented plenty of each.

The purpose in action research is to learn from experience, and apply that learning to bringing about change (Dick, 2000). Goethals, Howard, and Sanders argued that it is through reflective practice that a deeper level of learning occurs; in this case deeper understanding of the computerized seamless V-bed knitwear design and manufacturing process as a socio-technical system (2004, p. 2). In this way, learning and change build on each other, in part because all learning requires some level of reflection as the regular examination of one’s experience to assess its effectiveness (Marsick, 1988, p. 192)(Figure 47). To bring forward ideas, the reflective practice used in this research included asking questions such as: “What could be developed?”, “How do I go about it?”, “What resources are available?”, “How do I move forward?” (SFLQI, n.d.)

Reflection’ is an important tool of action research and research into organizational development. The ability for the researcher in this project in her role as ‘participant’ to ‘reflect’ in/on actions, outcomes, strategies, decisions and all other ways of participating organizationally in the processes under scrutiny is central to the data collection, analysis, and findings of this PhD.

Schön brought ‘reflection’ into the center of an understanding of what professionals do in 1983 in ‘The Reflective Practitioner’ (1983). He introduced the dual notions of reflection-in-action, and reflection-on-action (Smith, 2009). ‘Reflection-in-action’ can be interpreted as thinking again about a problem, in a new way whilst undertaking the action, whist ‘reflection-on-action’ as a reflection consciously undertaken after the event and often documented (Waters, 2005).

In this PhD, reflection on fashion design projects using the Shima Seiki WholeGarment® knitting system was used to identify areas of improvement/change of the organizational arrangements and processes. Figure 47 illustrates how ‘reflective process’ is applied within the participatory action research paradigm of this study.

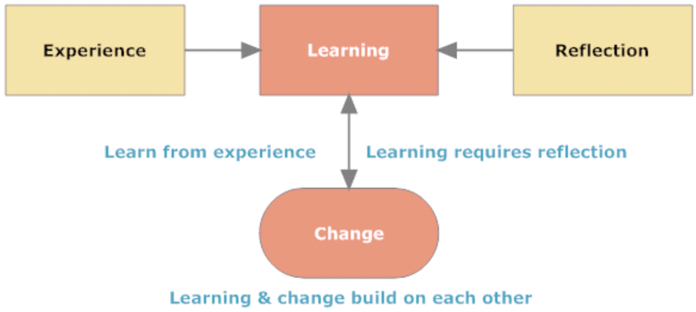


Figure 47: Single stage reflective learning

New knowledge was identified through undertaking the multiple knitting projects in a reflection, learning, and test process which one project led to another and one cycle of action-reflection led to another with knowledge and process development increasing via each cycle. The cyclic reflective process in Figure 48 was the basis for a learning and development in this project following a cycle similar to the Shewhart /PDCA cycle (Deming, 1986; Shewhart, 1931).

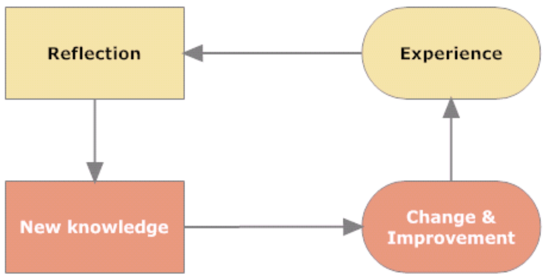


Figure 48: Reflective learning loop used in creating new knowledge and process improvement

Data collection and analysis in knitwear design projects

The researcher was involved as participant knitwear designer/knitting machine technician/knitting machine operator in eight wool projects using a Shima Seiki's WholeGarment® computerized seamless V-bed knitting technology for the design and manufacture of fabrics and garments:

- 'Design for Comfort' (twelve different fabrics created for five Western Australia designers for a national fashion show);
- Creating Outfits for the 'Wagin Woolorama Ambassador 2007';

- Cone-shaped Artifact (a knitted gigantic lamp shade planned for public display);
- Tube garments with Curtin students in 2007;
- Collaboration with an Italian designer Bianca Gervasio (exhibited at AltaRomAltaModa);
- Supervisory work with student designers;
- Creating Outfits for Dancers; and
- Tube garments with Curtin students in 2008.

Data gathered about the processes and activities of eight projects were initially derived from the investigation of emails created and received during the process of each project. The eight projects directly contribute to answer all different aspects of three research questions (Appendix 1 outlines each project).

During the research, a new approach to profiling of knitwear design projects was trialed using an applied process mapping technique that categorized activities into, 'an (activity) verb + noun/object + qualifier' combinations. This approach was developed for workflow assessment in the military (Berry, 1998). It was trialed in this research to help formalize descriptions of the project processes and events and make them more visually accessible. This 'verb + noun + qualifier' combination is similar to Tim Berners-Lee model that underpins the Resource Definition Framework that forms the basis of the Semantic Web (Herman, Swick, & Brickley, 2009). The researcher found the approach was mainly useful because it helped the researcher bring back her memories in a more structured way. It offered her simple and easy steps to document the process, and it facilitated further analyses of all the processes of the projects (see Appendix 1).

Critical incident analysis

Critical incident analysis was used in the research as technique that refines the reflective action research process by identifying critical incidents, and analyzing them with the expectations that learning and new knowledge and process improvement will result (Moon, 2006, p. 155). A 'critical incident' can be seen as:

> *… an event which made you stop and think, or one that raised questions for you. It may have made you question an aspect of your beliefs, values, attitude or behavior. It is an incident which in some way has had a significant impact (Monash University, 2009).*

Identifying and analyzing critical incidents in the design and manufacturing processes in each knitwear project focused the researcher's attention on data about those significant issues that gave most insight into situations and how to improve them. According to Gremler (2004), critical incidents can be gathered in various ways. In this research, critical incidents were identified from the researcher's own reflections and experiences in undertaking the real world knitwear projects as documented in diaries, notes, emails and knit data files. The **Critical Incident Technique (CIT)** is a set of procedures used for collecting direct observations of human behavior that have critical significance (Flanagan, 1954). CIT was using in this research as a guide to determine the critical incidents, to collect the details of critical incidents, and identify the issues and opportunities for improving the high-fashion computerized knitwear design and manufacturing processes.

Identifying critical incidents from emails

Critical incidents were identified by conducting a systematic scan of email contents as described in Appendix 2.

Analyzing emails of critical incidents

Analysis of emails of critical incidents provided information for each project about:

- The researcher's activities;
- The researcher's objective/aim for each activity;
- The researcher's role for each activity;
- Categories of activities;
- The bridge to studio activities;
- The researcher's studio activities; and
- Design processes of projects.

Bringing all emails into the same format proved to be problematic across the different email servers and email clients (different versions of Outlook, ldapi, pop3, and webmail). Microsoft Office Outlook 2007 was used to bring the emails into the same format emails because of its ability to convert Microsoft Office Outlook emails into Microsoft Office Word files which facilitated both analysis and backup of data.

There were twenty (20) steps involved in the process to identify and analyze emails of critical incidents and to analyze the emails for each project. The process is detailed in Appendix 2.

Process mapping

A key aspect of the research was to identify, record and compare the new innovations in design and manufacture processes developed in this research with the conventional design and manufacture processes of computerized seamless V-bed knitwear systems. *Process mapping* (also known as *process charting* or, sometimes, *flow charting*) is a useful tool to identify, describe, and make visible these details of design and manufacturing processes in ways that enable changes to be identified and reported (Ad Esse, 2006). Process mapping was used in this research for visual representation of processes, workflows and activities to document and to analyze them. A process map 'visually depicts the sequence of events to build a product or produce an outcome' (Strategos Inc., 2009). It provides a diagram of workflow to bring forth a clearer understanding of a process or series of parallel processes (Ahoy, 1999). *Process mapping* is one of the oldest, simplest and most valuable techniques for making visible and streamlining work. Flowcharts provide a visual convention for process mapping in that a flowchart is a graphical representation of a process or the step-by-step solution of a problem, using suitably annotated geometric figures connected by flow lines for the purpose of analyzing, designing, documenting or managing a process or program in various fields (Software and Systems Engineering Vocabulary (SEVOCAB), 2006). Process mapping and flowcharting fit together well, and are regarded as members of the same family of approaches (TRIASTER, 2008).

Data: Emails

The high level of email exchanges with sundry stakeholders of the knitwear projects undertaken in this research acted as date stamped records of micro and macro issues in focus at different times of projects. Emails of critical incidents identified particularly significant foci of attention. For data triangulation, the multiple elements of this email data were brought together in ways to check consistency by triangulation, and to identify data conflicts.

Emails were the dominant communication media in all activities. Five-hundred and fifty-four (554) emails across three e-mail accounts provided the background data about the projects. The three email accounts used in the research projects were: an email account at Curtin University of Technology, an email account at DAFWA, and an informal personal email address at a Korean portal website (www.nate.com, previously, www.empas.com).

Collating the email accounts into a usable resource proved to be complex and non-trivial. The detailed processes for collating the data from emails are described in Appendix 2. There was interdependence between the data collected that enabled triangulation and data checking. For instance, analysis of 'emails and printouts of critical incident emails,' were partly dependent on the other data sources. Analysis of 'the socio-technical system of knit data files on the USB drive,' was partly dependent on the collection of 'corresponding *KnitPaint* design folders of knit data files'. This in turn was partly dependent on data sources such as 'actual fabric/garment samples, work diaries, design specification sheets, size specifications files and printouts of the size specifications file, and electronic images.'

Data: Knit data files

All fabric/garment design activities on the Shima Seiki SDS-ONE® system resulted in creation of knit data files by the Shima Seiki SDS-ONE® design software system to knit the fabric/garment design outcomes using the knitting machine (see Function and formation of knit data in Chapter 4). The knit data files are the code instructions to the knitting machine necessary to knit a fabric or a garment. Each design activity required the production of different types of fabrics or garments. Knit data files were created in the Shima Seiki CAD system to produce those samples on the knitting machine. The knit data files of each fabric/garment sample were recorded and stored in the SDS-ONE® CAD system and also on a USB drive which was used to physically transfer the knit programming code to the knitting machine to knit the fabrics or garments. In earlier phases in the research, the technology was different. Knit data files were saved and transferred onto 3.5" floppy diskettes and later 3.5" magneto-optical discs following the machine manufacturer's built-in specifications. Later knit data files utilize the maximum of 2 Gigabyte (GB)[2] storage space while the earlier floppy diskettes allowed only 1.44 Megabyte (Mb)[3] of data space and the mid-term optical disc storage made available 720

[2] 1 GB=1,024 MB

[3] 1.44 MB floppy diskette can store 1,474,560 bytes of data. MB in this context means 1,000×1,024 bytes.

Megabyte (Mb)[4]. For analysis, the knit data files on older storage media were brought into the same space and structure as the newer knit files. To do this, they were copied onto a larger format USB drive that stored the knit data files from all of the projects together.

Analysis of the knit data files focused on:

- The number and type of *KnitPaint* fabric/garment pieces designed, programmed, and tested on the knitting machine during the period (26/01/2006 ~ 29/10/2008); and
- The sequences of studio activities and processes and how these aligned with eight projects identified from email investigations.

Creating file lists of the large number of files in the complex pattern of *KnitPaint* folders required systematic examination of the data file names and their last modified dates. This required copying them backward and forward between the USB device and the apparel workstation design software to enable the knit data files to be sorted according to their last modified date. This latter step was necessary as it enabled the researcher to bring the date values to a similar datum in order to establish sequences of events. Otherwise, the date of the design folders and knit data files were incorrect because the apparel workstation system date was automatically reset each time the Shima Seiki design software was upgraded each year.

It proved easier to review printouts of listings of the knit data files rather than electronic copies. This was because of the complex structure of the data. The eight operational steps used to identify the data embedded in the 'file lists of *KnitPaint* design folders' are described in Appendix 3.

***KnitPaint* design folders**

A new parent folder was created for each studio activity on the SDS-ONE® CAD apparel design workstation system. Each *KnitPaint* design folder that held a set of files in regard to a fabric/garment design was copied into the relevant parent folder and multiple *KnitPaint* design folders were collected under each parent studio activity folder. These were used to identify the types of programming techniques involved in each project.

[4] 720 MB optical disc can store 737,280,000 bytes of data. MB in this context means 1,000×1,024 bytes.

The *.dat files of each corresponding *KnitPaint* design folder of a *.000 file (now without file extensions) were systematically examined in terms of the knit data file sub-types to identify type of knitted designs, type of fabric texture layout, type of pre-registered garment shapes used in the case of a WholeGarment®, and type of discernible design details. This involved reviewing a substantial amount of data. To give order to this process, a 'Microsoft Office Excel worksheet' was created that contained all relevant information about types of design and the programming techniques used in each knitted design of each *KnitPaint* design folder. The twenty operational steps that were needed to collate these are described in Appendix 3. During this collation, triangulating data were referred to. These included data from actual fabric/garment samples, work diaries, design specifications sheets, size specifications files and printouts of the size specifications files, and electronic images.

Data: Fabric and garment samples

A large number of fabric/garment prototypes were knitted using the knit data files. Many of these prototypes were developed to *1st sample*, manufactured in the research and collated into a large library of garment samples (Figure 49).

Figure 49: Fabric/Garment samples

The researcher found that reflection on and of these fabric/garment samples was a powerful research tool for reflection because they refreshed the researcher's memory on studio activities as well as other design activities.

Once knitted, all fabric/garment samples were catalogued and labeled consistently, and then stored in the DAFWA knitting studio with the Shima Seiki knitting system. In part, this was for archiving and displaying and in part the readiness for their further development, if necessary the labels held the following data:

- Sample creation date: date/month/year;
- Sample name;
- The *KnitPaint* design folder's name and its parent 'studio activity' folder's name to indicate where it was stored in the SDS-ONE® CAD system;
- The gauge of the machine needle used for the knitting: 14GG or 8GG;
- Yarn count and number of strands in yarn;
- Yarn carriers in use;
- Knitting speed (meters/second);
- Overall knitting time;
- Washing condition;
- Post-wash treatment; and
- Whether or not the fabric/garment was being displayed in public.

Data: Work diaries

Throughout the research, the researcher maintained work diaries of all activities as a knitwear designer, knitting machine technician, and operator. These diaries documented the researcher's design development practice and workflow, critical incidents, and any note-worthy issues in designing and knitting to commissioned work (projects). This work diary approach was already well developed by the researcher who has had a long-term habit of keeping such (visual) records because of her professional experiences and educational backgrounds. A variety of work diary formats are used: computer screenshots, note-taking, sketches, paper-folding, photographing, or print-outs without a specific order was employed (see Figure 50 for images of work diary).

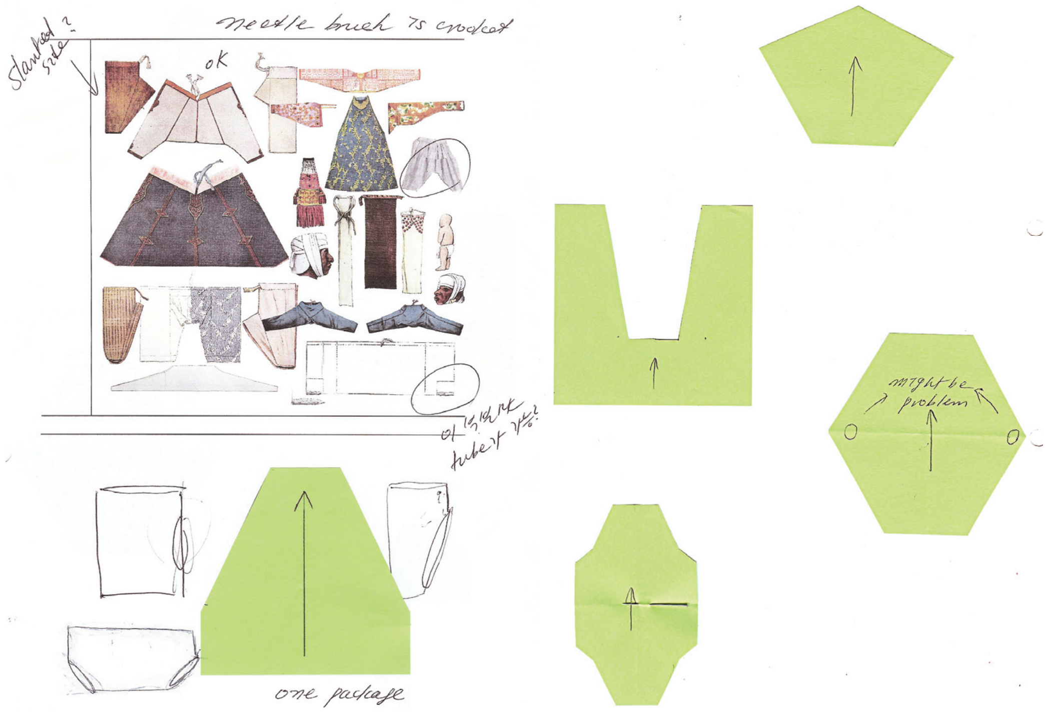


Figure 50: Work diary

In these work diaries, work-related information was recorded as a 'set', according to each *KnitPaint* design folder, when there was something significant in designing, programming, or operating the knitting machine. This was done especially, when things went particularly well or proved to be difficult or particularly time-consuming. Information recorded in the work diaries in this manner included:

- Printed computer simulation image of a fabric design, if necessary;
- Printed computer simulation image of a WholeGarment® design, if necessary;
- Printouts of knit data files of a knitted design with any knitting adjustment;
- Printouts of the size specifications file of a WholeGarment® pattern; and
- Yarn sample(s).

Work diaries were also useful to bring back the memories on programming or technical matters and to identify any issues that may potentially have been overlooked.

Data: *Design specifications sheet*s

A *design specifications sheet* is a document that summarizes all the design details necessary for a garment construction and manufacture. It includes graphic descriptions, size information of the sample, instructions for manufacture, and listing of materials for making *1st sample*.

Design specifications sheet are active working document that designers or others involved in sample/garment production make notes on them, and record on them any changes regarding sample/garment production. As a work habit, the researcher made detailed notes on the *design specifications sheet* about how she interpreted designs to program knit data files on the SDS-ONE® CAD system. Any modifications made when meeting with designers or while programming on the CAD system or knitting on the machine were also recorded on the same *design specifications sheet* to record each and every modification.

In this research, examples of *design specifications sheet*s from an internationally famous professional knitwear designer and from student designers were collected and stored along with printouts of the size specifications.

Data: Size specifications files

Size specifications files are the master size sheets for individual computerized seamless V-bed knitwear samples. Using the WholeGarment® system, each pattern developed via pre-registered garment shapes (see Creating a raglan sweater: design and manufacture in Chapter 4) must have its own size specifications file created (or use another WholeGarment®'s size specifications file). Body measurements or garment part measurements chart for each WholeGarment® pattern are recorded in the size specifications file for that design.

For every fabric and garment designed using the SDS-ONE® CAD system, each size specifications file was saved in a folder for each design in the SDS-ONE® CAD system for future use (D:\Sysd\size_specs). Changes in measurement chart to create original WholeGarment® patterns or derivatives of the original WholeGarment® patterns were kept for future use on the printouts of the size specifications file. Derivatives of each original size specifications file were saved with their modified values under serialized file names in the folder (D:\Sysd\size_specs).

Experience showed that referring to printouts of size specifications files was essential to reduce trial and error and create better garment shapes using the computerized seamless V-bed knitting system. Size specifications are computer-generated and on the Shima Seiki WholeGarment® system the size specifications function is embedded in the SDS-ONE® CAD data.

The unsystematic structure of files in the SDS-ONE® CAD system and the difficulties in accessing them means it is far more efficient for the knitwear designer, knitting machine technician, and operator, to have size specifications files printed out. In other words, the printouts of size specifications files were necessary for easy checkup because of one drawback of the software's features – there is no direct access to size specifications files, except to re-transit the length of the built-in design and production workflow.

Data: Electronic images of fabrics and garments

The fabrics and garments developed for the eight wool projects were professionally photographed using professional agency models. Electronic images of all fabrics and garments were stored in digital image files in the researcher's computer and on CD ROMs. These professional images were an excellent educational tool that demonstrated how theoretical design concept became shaped by technology through the garment development process and offered motivation to student designers and stimulated their creativity.

Data: Notes on the Shima Seiki training of the researcher in Japan

Shima Seiki provides comprehensive training programs at its on-site training facility, Total Design Center. The researcher undertook three intensive formal training periods at the Shima Seiki training Center in Japan during the period from 8th of May to 9th of June in 2006, (08/05/2006~09/06/2006), from 9th of January to 19th of January in 2007 (09/01/2007~19/01/2007), and from 2nd of July to 13th of July in 2007 (02/07/2007~13/07/2007).

The training program is intended to provide instantaneous knitting satisfaction to trainees in industry and to offer guidance and short-cuts to urgently resolve knitting problems.

These training programs are not however well suited to trainees with design background like the researcher and not unexpectedly the researcher found it hard to immerse herself into these technician-oriented training program. The researcher needed to identify ways of using built-in features to produce knitted fabric and garment samples with high-fashion. The researcher's notes and reflection on training reflect this. Highly detailed notes were kept while undergoing training in Japan with Shima Seiki. These notes were intentionally highly detailed because the research work and teaching at the knitting studio at DAFWA back in Perth took place with limited technical support. All of the researcher's records of this training work, including knit data of designs undertaken at Shima Seiki in Japan, were copied to magneto-optical discs and brought back Australia with the researcher. The training work data files were on seven magneto-optical discs: five from the first training and one each from the second and third training period. These included five knit data files from the first training period, and one each from the second and third training periods.

To identify changes in training to educate high-fashion knitwear designers in creating *1st sample* prototypes using computerized seamless V-bed knitting technology, three training notes, one from each training period, along with training data files were reviewed in detail. The same notes and files were also reviewed as part of the analysis for improving the high-fashion knitwear design process on the Shima Seiki.

Data: Teaching of fashion design students

Starting from 2007, to introduce the computerized seamless V-bed knitting technology, part of one of the core units for Curtin Fashion and Textile Design students involved training sessions in making tube based garments using the Shima Seiki knitting system at DAFWA . There were five consecutive formal sessions per semester.

Each tube garment training program was structured as kind of crash educational course because the design and manufacture of knitted garments produced by collaboration between student designers and the researcher had to be achieved to high-fashion level in only four formal sessions. The students worked on a tight class-schedule and were taught and monitored in a strict manner. During each of these sessions, short anecdotal notes were made about each session by the researcher while teaching the students how to design knitted garments and produce samples on the Shima Seiki knitting system. These notes were related to students' assessments as well as the research and because of their academic nature were kept in a separate section of the researcher's work diaries. Class notes used for teaching were also examined to identify changes and improvements for all aspects of sessions.

In addition, the researcher created a PowerPoint presentation file for public presentation on using the computerized seamless V-bed knitwear technology using the Shima Seiki knitting system as an example. This PowerPoint file evolved into different presentations for several different events. Scripts of the Power Point presentation were made to deliver the presentation. Any changes in the education process, according to the needs of the presentation, were kept on these scripts.

The PowerPoint presentation files and scripts of PPT presentation were reviewed to identify changes needing to be made to educate fashion industry people on computerized seamless V-bed knitwear design and manufacture technology.

Triangulation of Data and Analyses

Triangulation between and across data sources was used to avoid errors and fill in any gaps. Contribution to the analyses from each data source is described in Table 8.

Table 8: Contribution to analyses from each data source

Data source		**Analysis**
(Primary data source): Emails and printouts of critical incident emails: Mapping out eight projects	(Major data source): Reflections on the wool projects	The researcher's overall activities The researcher's objectives/aims for each overall activity The researcher's roles for each overall activity Categories of overall activities The bridge activity to studio activities The researcher's studio activities Design processes of projects
Lisocio-technical system of fileslisting of knit data files on USB drive		Number of SDS-ONE® *KnitPaint* fabric/garment designs that were designed, programmed, and then actually tested on the knitting machine during the period (26/01/2006 ~ 29/10/2008) The sequence of studio activities, whether or not they match the sequence of eight projects drawn from email investigations
Corresponding SDS-ONE® *KnitPaint* folders of knit data files		Types of programming technique involved – i.e., type of knitted designs, type of fabric texture layout, type of pre-registered garment shapes used in the case of a WholeGarment®, and type of discernible design details
Actual fabric/garment samples, work diaries, *design specifications sheet*s, size specifications files and printouts of the size specifications files, and		To serve the purpose of creating dialectic to analysis of data source, 'corresponding SDS-ONE® *KnitPaint* design folders of knit data files'.

electronic images of work		
Teaching notes		Changes that need to be made for improvement in all aspects of sessions for tertiary level students
Training notes and training data files		Changes in training that are required in order to make high-fashion knitwear designers more efficient in creating *1st sample* prototype using WholeGarment® knitting technology while improving the high-fashion knitwear design process on the Shima Seiki.
PowerPoint presentation files and scripts of PowerPoint presentation		Changes that need to be made to educate fashion industry people on the computerized seamless V-bed knitting technology

CHAPTER 7: Findings: New Design Process, Role, and workflow Model for Computerized Seamless V-bed Knitwear Creation

The outcomes from this research are complex and include proposals for changes to design process, workflows, roles, design methods, high-fashion knitwear design education programs and industry-wide changes across computerized seamless V-bed knitting, which is itself causing radical changes to fashion knitwear production. Computerized seamless V-bed knitting systems, such as those by Shima Seiki and Stoll, are radically transforming the mass-market knitwear industry. Their intended effect is to reduce design and manufacturing costs, shorten the time needed for design and manufacturing, and enable manufacturing of mass-market retail knitwear close to point of sale. Computerized seamless V-bed knitting systems have well identified problems in design process in anything other than routine knitwear production. This is due to poor integration of the tasks of knitwear designer, knitting machine technician and knitting machine operator and deep tensions between these roles as detailed in Chapter 5. Computerized seamless V-bed knitting machine manufacturers have focused their attention on attempting to eliminate the role of the knitwear designer and reduce the role of the knitting machine technician to 'programming knitting machines to maximize knitted output'. Both make sense in terms of economically producing a limited range of simple mass-market knitwear. It results in restriction to creativity of knitwear businesses using the computerized knitting systems to a choice between standard garment shapes (sweater, pull-over, and skirt etc.) with options for minimal variations in details, decoration and color.

Computerized seamless V-bed knitting technology, however, offers significant benefits for the high-fashion knitwear sector as it permits rapid production of one-off garments or small runs. The high-fashion knitwear sector, however, requires more creativity better alignment with high-fashion knitwear design and production culture than is currently offered by the design and manufacture processes of computerized seamless V-bed knitting system manufacturers. Design and manufacture of high-fashion garments is essentially dependent on creative human high-fashion knitwear designers. In the high-fashion knitwear sector, garment variety is high; yarns are harder to knit; garment shapes are often unusual and complex; production numbers are small; manufacturing needs to result exactly in the shape, feel, texture and drape of the garments as designed; and there is a need to create multiple test samples of fabrics and garments during the design process. These are all issues that would be expected to require drawing on the expertise of high-fashion designers and knitting machine technicians. This situation for high-fashion is at odds with the ‘automated’ designer-less knitwear design approach and manufacturing processes that are the focus of computerized seamless V-bed knitting systems in the mass-market knitwear sector for which it was primarily developed. To date, a compromise process with many problems has been developed. High-fashion knitwear designers produce designs that they hand over to knitting machine technicians to program. This compromise process fails in many ways as detailed earlier in Chapter 5 and places dependence on successful design on the machine technician rather than the knitwear designer. In short, the while computerized seamless V-bed knitwear design and manufacture offers great potential for the high-fashion knitwear sector, the design and manufacturing processes developed by computerized seamless V-bed knitwear manufacturers do not work for the high-fashion sector.

Introduction to findings

The purpose of this PhD has been to explore, identify, and test potential solutions to the above research problem of improving the computerized seamless V-bed knitwear design and production process for high-fashion knitwear to reduce or remove the tensions and contradictions in the workflow involving fashion designers and knitting machine technicians.

In this PhD research, the research findings emerged as a result of critical and reflective analysis of activities in which the researcher undertook the roles of knitwear designer, knitting machine technician, knitting machine operator and design educator and, later, as educator of new students learning about applying the findings in learning to use computerized seamless V-bed knitting technology. Figure 51 shows the main aspects of the research.

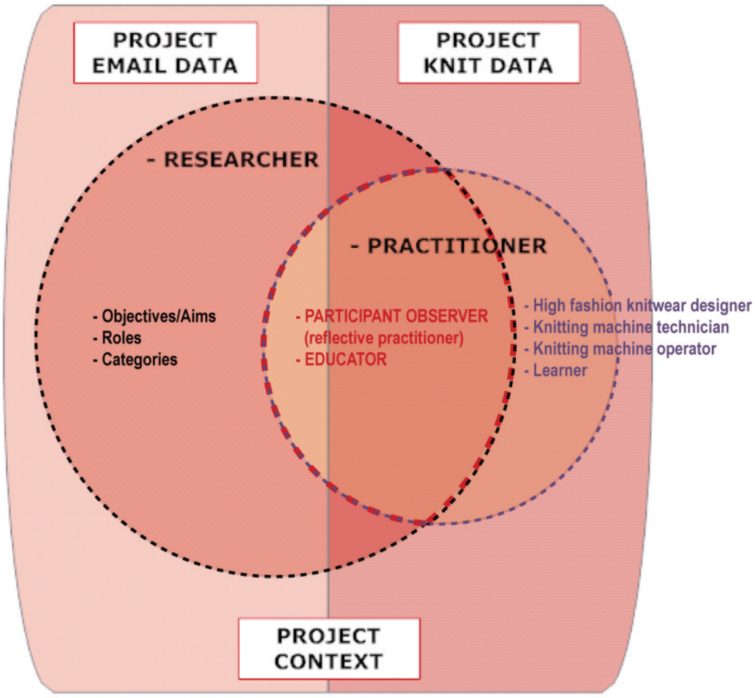


Figure 51: Aspects of the research

Analysis of emails was an effective tool for understanding the workflows and mapping project processes. This was supplemented with and triangulated against electronic data relating to the project knit data files, which provided time and date stamped information about designs. Together, these provided the basis for developing the new workflow processes, findings and outcomes in this PhD.

Overview of research outcomes

The primary outcome of the research was the development of new integrated high-fashion knitwear design and manufacturing process centered on the knitwear designer with minimal dependence on the knitting machine technician, whose role is refocused on maximizing knitted output production rather than design support.

In addition are a wide range of findings and lessons learned particularly from the practical aspects of the research. These form six groups as listed below.

1. New integrated high-fashion knitwear design and manufacturing process;
2. Process mapping of design and manufacturing processes;

3. Development of new design methods – envelope (design solution space) and software interface;
4. Lessons learned from projects;
5. Lessons learned from training undertaken by the researcher; and
6. Lessons learned from teaching.

An overview of the process of development of the findings is shown in Figure 52.

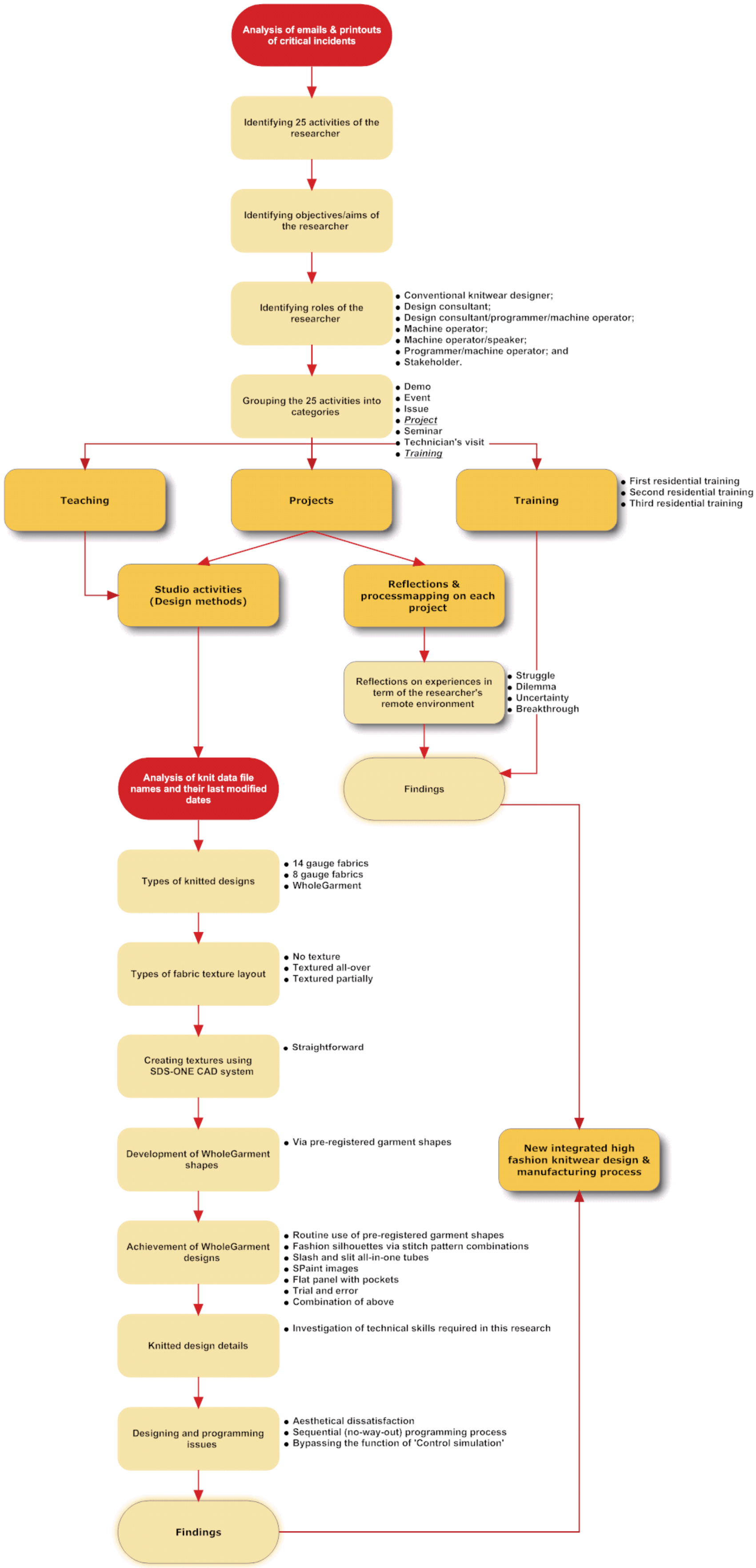


Figure 52: Relationships between research findings

New integrated high-fashion knitwear design and manufacture workflow process

The research resulted in the development of both a new alternative knitwear design and manufacturing process and new knitwear design methods of use in computerized seamless V-bed knitting. Together these appear to resolve many of the problems for the high-fashion sector of the existing problematic design and manufacturing processes of computerized seamless V-bed knitwear design and manufacture.

The primary changes proposed in the new integrated computerized knitwear design and manufacture are in three areas:

- Changes in knitwear design processes to the point of 1st sample;
- Changes in the relative balance of skills needed by knitwear designers; and
- New strategies and design methods for using the design and manufacturing software and hardware tools available in computerized seamless V-bed knitting systems.

This new integrated high-fashion knitwear design and manufacturing process for computerized seamless V-bed knitting systems not only addresses most of the identified problems for the high-fashion sector, it also better integrates with the roles and skill sets of knitting machine technicians and knitting machine operators with those of knitwear designers. In this sense, it not only resolves the problem of the high-fashion computerized V-bed knitwear sector, it also provides a workflow process for improving mass-market knitwear via increased designer involvement.

Figures 53 and 54, and Table 9 below illustrate this new integrated workflow.

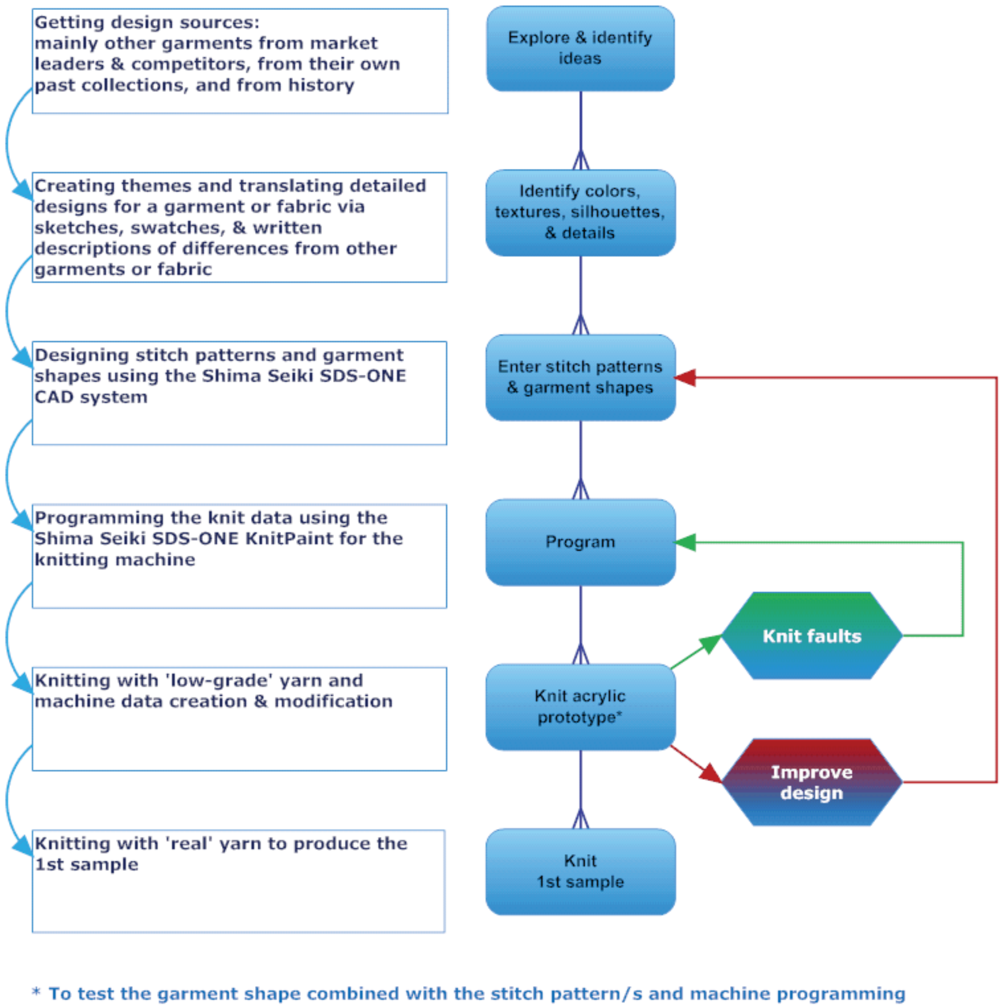
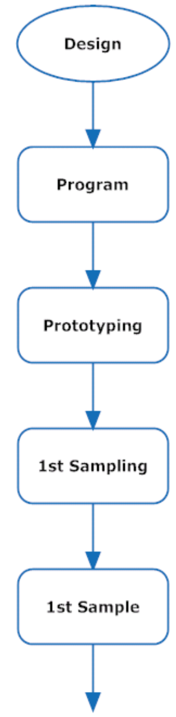
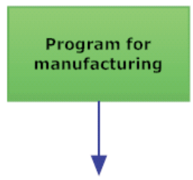
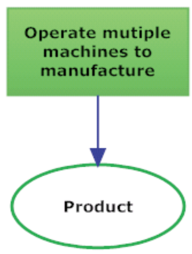


Figure 53: Knitwear designer's task workflow (simplified) to *1st sample*

In the above process to the production of *1st sample*, the knitwear designer undertakes all roles and activities of design, knitting machine management and operation. The new knitwear designer role includes all those tasks previously undertaken the knitting machine technician and knitting machine operator (Table 9).

Table 9: Work organization model for the new integrated high-fashion design and manufacturing knitwear process

<table>
<tr><th>Product development stage</th><th>Group of workers</th><th>Product development process</th></tr>
<tr><td>1st sampling</td><td>Knitwear designer</td><td>
</td></tr>
<tr><td rowspan="2">Production</td><td>Knitting machine technician</td><td>
</td></tr>
<tr><td>Knitting machine operator</td><td>
</td></tr>
</table>

At the point of handover of *1st sample*, the knitwear designer can provide the knitting machine technician and knitting machine operator with both machine code for knitting production and a physical sample of the garment as intended to be produced. From that point on, the technician can optimize the knitting machine program code and data for mass production.

The practical detail of the knitwear designer's role in this new integrated computerized V-bed knitwear design and production process is shown below in Figure 54.

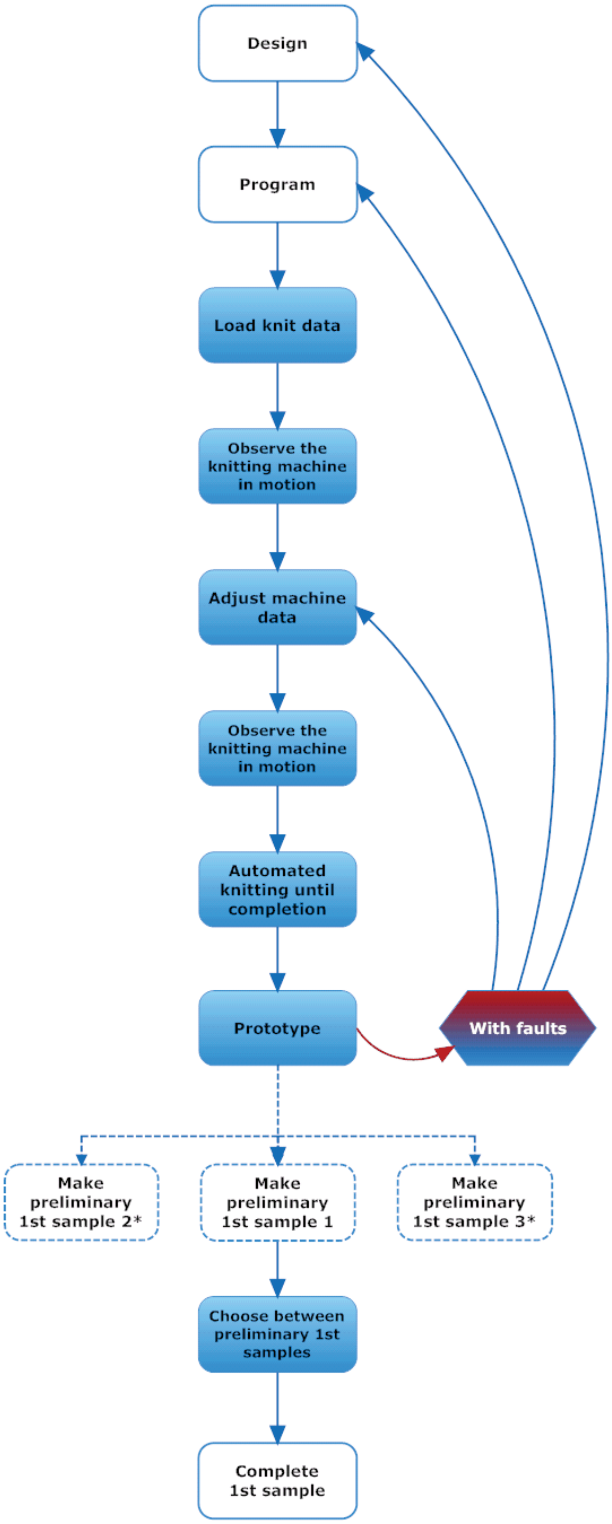


Figure 54: Practical details of new knitwear designer's role in new integrated high-fashion knitwear design and manufacture process

This approach enables the knitwear designer to have total control over the designs and design outcomes and the knitting machine technician and knitting machine operator to have control over production.

Process mapping of design and manufacturing processes

During the research, the workflow processes of different aspects of knitwear design and manufacture were mapped using flowcharts and tables. This was done to better understand existing processes for knitwear design and manufacturing and to establish a basis for identifying potential solutions that would resolve the identified problems with the high-fashion sector's use of computerized seamless V-bed knitwear technology.

Surprisingly, most existing process maps of workflow in the knitwear industry in general overlook the complexity involved the design/prototyping phase and focus in proportionately much more detail on steps in manufacturing, logistics, line/collection planning, customer interaction, and business process improvement (see, for example, (Shanghai LONGXING knitting factory Co., 2010)) or focus on simplifying the design phase of workflow in order to reduce user's exposure to technical complexity and programming.

The design-centered mapping of knitwear design and manufacture workflows developed in this PhD research appears to be a new contribution to this area. The researcher mapped the workflow processes of:

- Conventional knitwear design (Figure 55);
- Conventional computerized non-seamless V-bed knitwear design and manufacture (Figure 56); and
- Conventional computerized seamless V-bed knitwear design and manufacture (Figure 57).

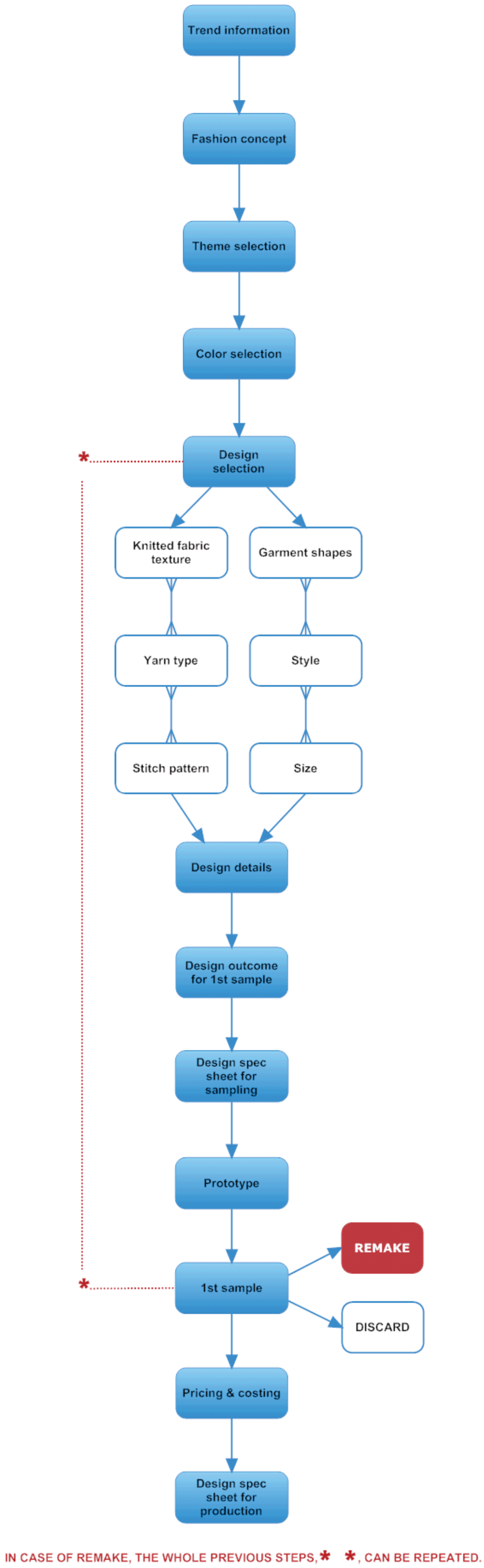


Figure 55: Conventional knitwear design

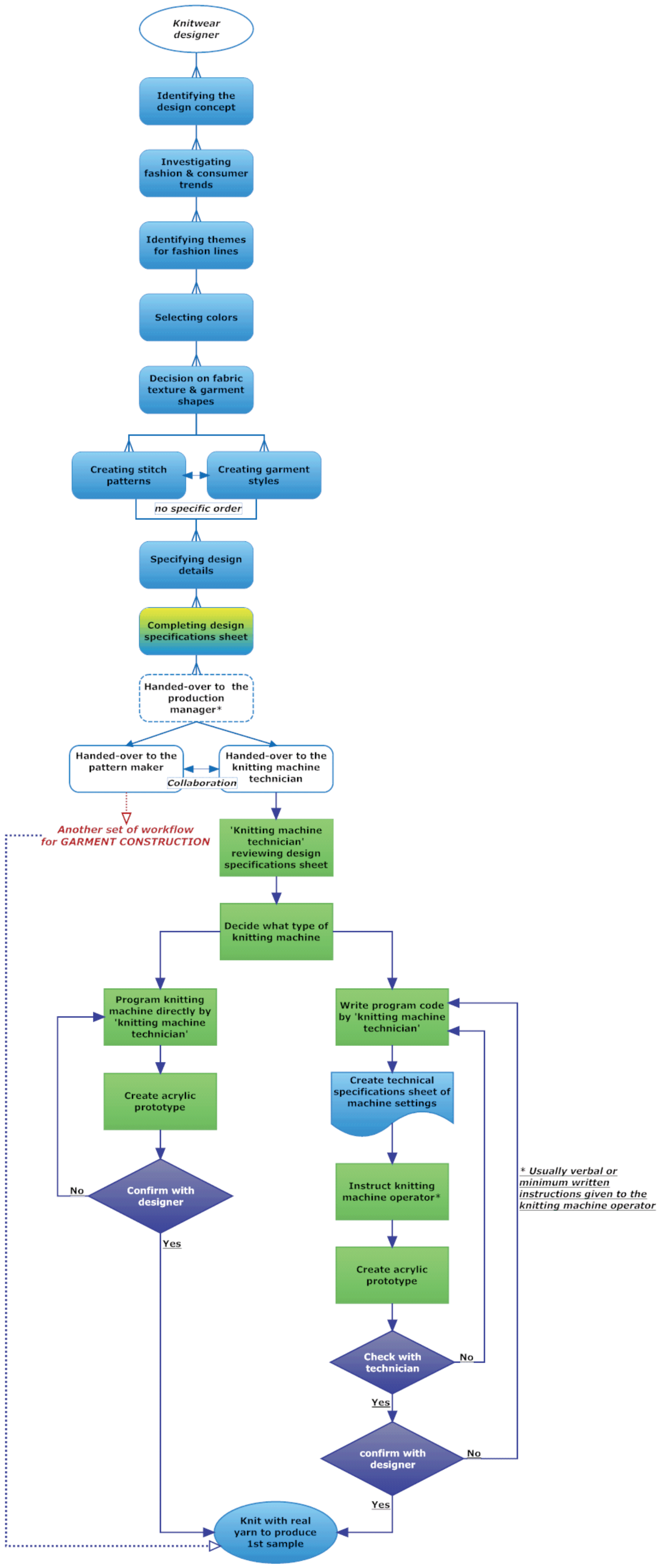


Figure 56: Conventional computerized non-seamless V-bed knitwear design and manufacture

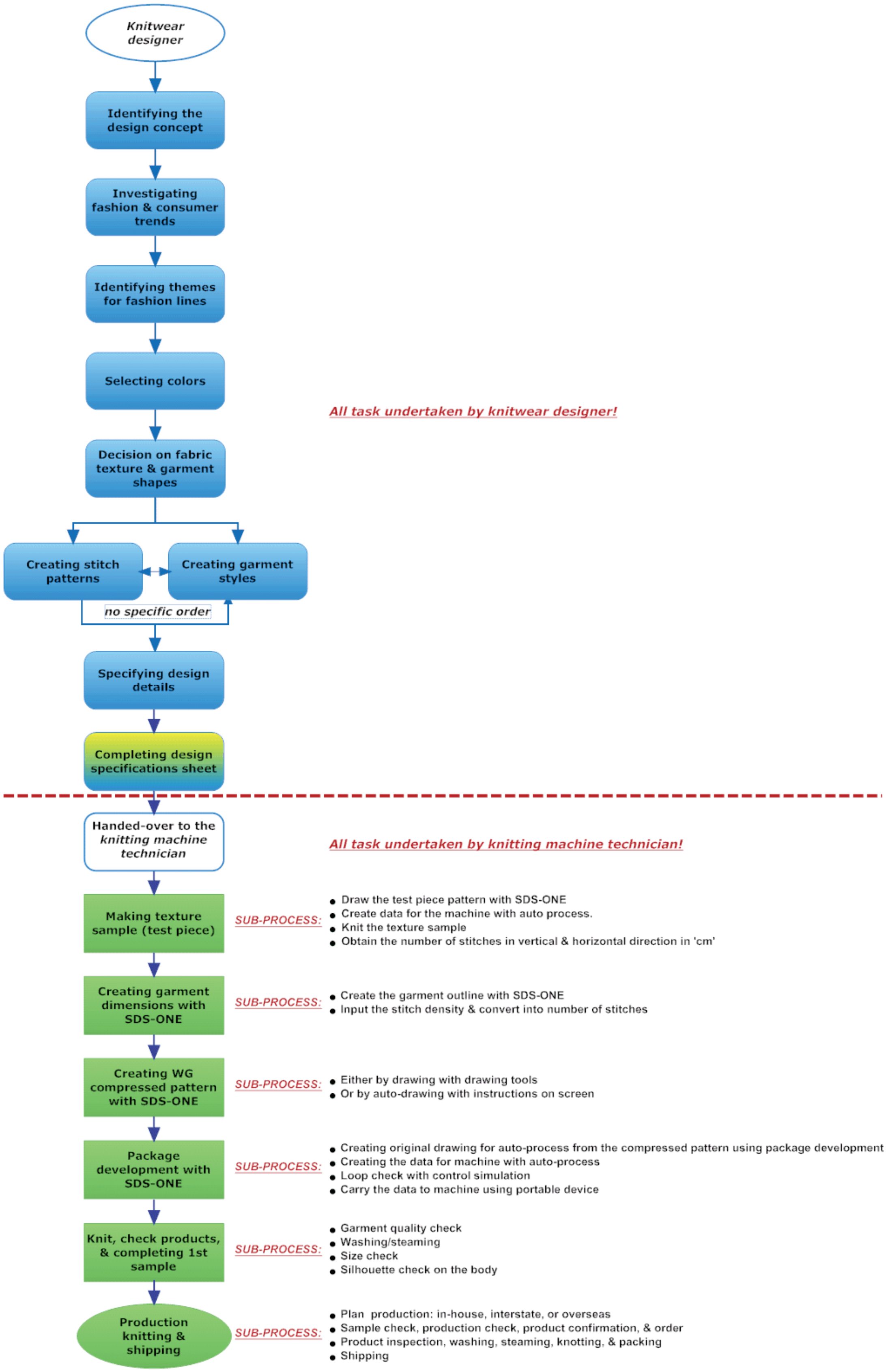


Figure 57: Conventional computerized seamless V-bed knitwear design and manufacture. Source: (Shima Seiki Mfg., 2008d)

Reviewing and comparing the above workflows reveals the basis of some of the problem issues in knitwear design and manufacture. It is difficult to achieve job optimization in conventional computerized V-bed knitwear design and production processes because of their complication in integration of craft, design, and technology. These process maps also reveal the path of increasing technicalization in ways that have led to the control over and management of knitwear designs being transferred from designer to knitting machine technicians. For example, knitwear designers are still included to the point of *1st sample* production in conventional non-seamless knitwear development process (Figure 56), but they are excluded and their jobs are taken over by knitting machine technicians after the design specifications hand-over in conventional seamless V-bed knitwear design and manufacture process (Figure 57).

Development of new design methods and strategies

Central to this research has been the development of design methods that extend to high-fashion knitwear designers the fullest benefits of the potential creative and production envelope of design and manufacture using computerized seamless V-bed knitting technology. This required identifying how high-fashion knitwear designers could use different design methods and strategies to modify and repurpose existing knitwear design and manufacture processes and software that have been primarily designed for mass-market knitwear design and production or use by technical engineering expert programmers.

During the research, seven classes of 'new' design methods were devised or identified that extend the design envelope of computerized seamless V-bed knitting technology (as implemented by Shima Seiki) to enable and open up creative opportunities appropriate to high-fashion. Each of these new 'classes' of design methods represents a strategy within which there are multiple design methods. It is expected that similar classes of design methods and strategies will be found in relation to the processes of other manufacturers of computerized seamless V-bed knitting technology, such as in products made by Stoll.

The seven classes of new design methods are shown in Table 10 below:

Table 10: Classes of new design methods

Class of design method	Linkage to pre-registered garment shapes	Predictability of garment silhouette	Number of tube piece/s required	Pre-registered garment shape/s used
Manipulation of routine methods	Yes	Predictable as a knitwear designer uses the intended pre-registered garment shape	One or more combined and integrated into one garment shape	Tight skirt Sleeve-less top Sweater/Raglan Pants Flared skirt Sleeve-less & Flared skirt Sweater/Set-in A Sweater/Set-in B
Fashion silhouettes via stitch pattern combinatorics	Yes	Predictable as a knitwear designer creates the garment shape	One tube	Tight skirt
S-Paint images	Yes	Predictable as S-Paint images combined with a conventional pre-registered garment shape	Two or more combined and integrated into one garment shape	Any geometric shapes programmable
Slash and slit all-in-one tube	Yes	Unpredictable as a wearer dictates the garment shape	One tube	Tight skirt
Flat panels with pockets	No	Unpredictable as a wearer dictates the garment shape	N/A	N/A
Combination of the above	Dependent on a knitwear designer's design intension	Dependent on a knitwear designer's design intension	Dependent on a knitwear designer's design intension	All of the above
Trial and error	N/A	N/A	N/A	Possibly all of the above

*N/A: Not available

Modification of designs via routine methods

Undertaking the knitwear projects confirmed that the simplest approach to creating unusual knitwear for the high-fashion arena using computerized seamless V-bed knitwear design is to creatively use the variety already available in the systems routine processes by using whatever variation and modification adjustments are available in standard processes. In the knitwear projects undertaken in this PhD, the modification varied from extreme (e.g. the AltaRomAltaModa pieces), to almost negligible (Wagin Woolorama 2007 Ambassador's outfits) (Figures 58 and 59).

Figure 58: An AltaRomAltaModa piece using fabric created during the research (AltaRoma, 2008).

Figure 59: Wagin Woolorama 2007 Ambassador's outfit. Source: Courtesy of Ms Crystal McIvor

For high-fashion designers who wish to transition to designing and prototyping using the computerized seamless V-bed knitwear technology, the simplest first steps is to create fabrics and garments using extreme modification of the existing computerized seamless V-bed knitwear routine processes and pre-registered garment shapes. The approach is in the limit restricted by the intent of the routine design system of the computerized seamless V-bed knitwear technology as a means of creating conventional retail style, rather than high-fashion garments. This results in this design method being highly restrictive for the high-fashion knitwear designer in terms of creativity and novel garment development.

Creating high-fashion garments silhouettes using stitch structure combinatorics

High-fashion garment shaping can be done using stitch patterns in different stitch structures to create a wide variety of garment silhouettes and fits (Figure 60).

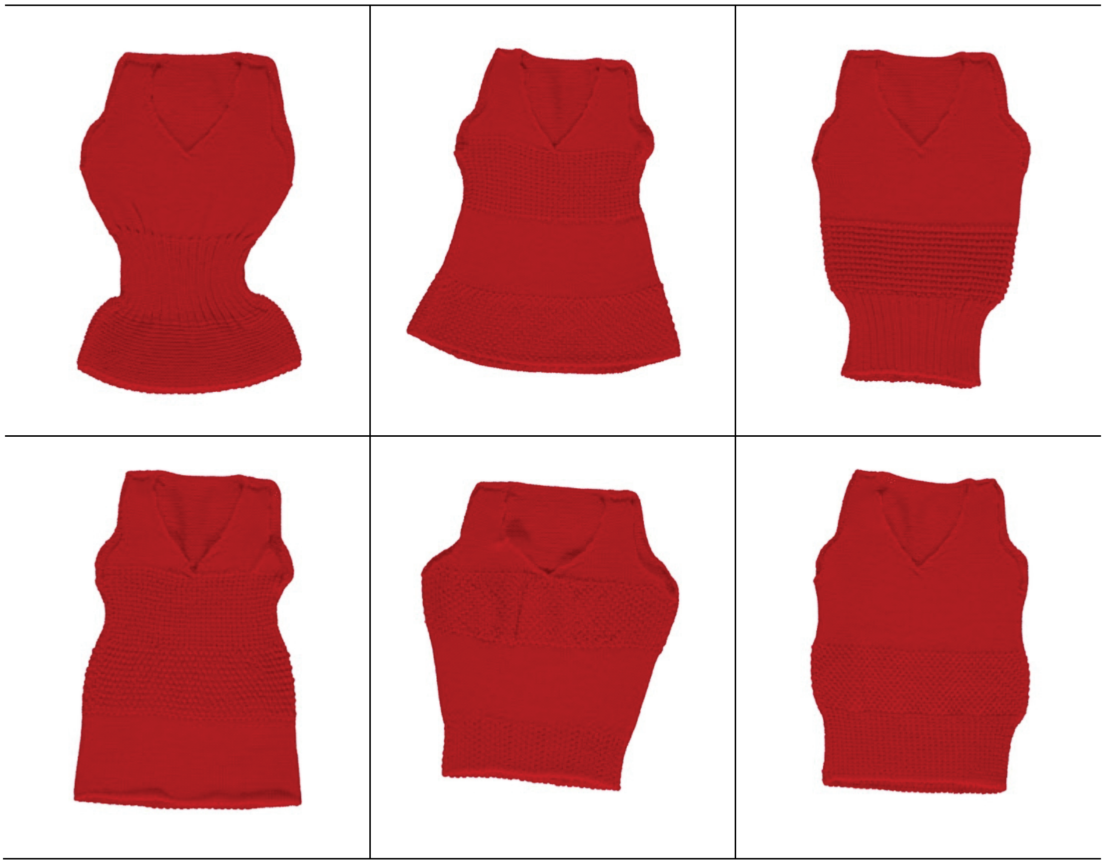


Figure 60: Six examples of garments shaped by three different combination types of stitch patterns

The effect occurs because different stitch structures occupy different space (and different in both wale and course dimensions) and have different physical properties (elasticity, drape, hand etc). Creating a garment shape in this way involves using different areas of a garment with different stitch patterns (e.g. knit stitch, purl stitch, float stitch, tuck stitch, and combination of these stitches) and using the fact that fabric width, length and elasticity are different for different stitch patterns.

In her Master's research, the researcher had earlier investigated and published (Yang & Love, 2009) this high-fashion knitwear technique into fixed needle count knitting and carried the techniques forward into this PhD.

High-fashion knitwear design method: Slash and slit tubes

Whilst at Shima Seiki in Japan undergoing training, the researcher requested the development of a special 'tube-based' set of package templates. The aim was to have a very flexible knitwear geometry that can be transformed into a range of clothing types. This unique template set is composed of several miniature tubes in relation to the body measurements combined with different opportunities to locate slashes and slits in various ways. In itself, it is not a garment; rather it is a highly modifiable template for making a variety of knitted geometric shapes that can be worn as garments. It can also be combined with other garment elements in unique innovative creative ways to create high-fashion outcomes. The template was programmed by Shima Seiki technicians at the request of the researcher.

The benefits of this design method are it brings unexpected results by creating unique garment shapes. A high-fashion knitwear designer wearer can stylize the garment shape whichever way s/he wants and often there are multiple ways of wearing the same garment. Much of the silhouette, shape, feel and positions of slashes and slits of such a garment are dependent on the shape and volume of the wearer's body. This means the final garment shape and silhouette can be hard to predict. An example of the outcome of this design method is shown in Figure 61.

Figure 61: Garment using modified tube template with slashes and slits. Source: (DAFWA, 2008)

High-fashion knitwear design method: combining three-dimensional garment primitives using S•Paint images software

A new design method for creating innovative high-fashion garment shapes emerged during this research from exploring using Shima Seiki's S•Paint images software to create new unconventional garment shapes by heavily 'incorporating' geometric shapes and 'attaching' them together to give unusual outcomes. This is a non-standard, extreme but effective repurposing of the S•Paint knitwear design software, which is more normally used as a starting point to create a fabric or garment piece.

There are several benefits of this design method. The use of S•Paint images to make small detail modifications to pre-registered garment shapes is a routine skill for anyone using the Shima Seiki SDS-ONE® system for creating simple retail garments (a similar software is found in Stoll machines). The new design method developed in this research repurposes that basic skill. It does this by using the S•Paint software to combine the simple pre-registered garment shapes available as standard in apparel design workstation garment 'library' with other shapes in unusual ways.

One option is to use new geometrically defined 'universal' shape templates such as the tube with slashes and slits template which the research arranged to have developed whilst in training at Shima Seiki in Japan. Another example that was particularly effective was to creatively combine pre-registered garment shapes with the WholeGarment® skirt template. Both massively increase the shape combinations available to the high-fashion knitwear designer and significantly extend the high-fashion design envelope of computerized seamless V-bed knitting technology.

An example of the use of this design method that uses the S•Paint software to combine different geometric and garment shapes is shown in Figure 62.

Figure 62: High-fashion garment created using garment elements combined using S•Paint image software. (DAFWA, 2008)

Flat panel with pockets

During her training at Shima Seiki, the researcher also requested Shima Seiki technicians to program another ‘universal’ template. This was intended to be used to extend the creative high-fashion envelope of the computerized seamless V-bed knitwear design and manufacturing system in a similar way to that achieved by the tube template with slashes and slits.

In this case, this new ‘universal’ template comprised a highly modifiable arrangement of flat shapes rather than tubular similar to a simple apron with pockets. It was however programmed as a WholeGarment® garment template which enabled it to be combined with other WholeGarment® template elements and using the V-bed seamless knitting technology also enabled it to include a pocket/pouch shape. The pattern topology for the template is simple as shown in Figure 63 below.

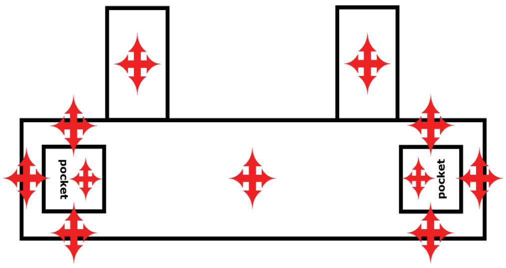


Figure 63: Image of flat panel apron pattern template

The benefits of this simple shape are that it can be modified in a flexible manner to have widely different clothing roles by increasing and decreasing the lengths and widths of the different elements and changing their position. Similar to the tube template with the slashes and slits, this flat panel template can also be ‘attached’ using the S•Paint software in the computerized design phase to routine pre-registered patterns from the garment library in a variety of ways, can be further shaped and structured by appropriate choices of stitch patterns, and even differently shaped elements of the tube template. For the knitwear designer, the geometric simplicity of this template makes it easier to envisage creative garment possibilities both on its own and when combined with other garment templates. It has an additional benefit as a design method that it introduces a means by which other garment patterns can be creatively reconstituted.

An example of its use is shown in Figure 64.

Figure 64: Apron top

Design method: Combinations

Increasing and extending the range of possible pattern combinations increases the creative high-fashion potential of the computerized seamless V-bed knitwear design and manufacturing systems and extend the design envelope of the knitting technology for high-fashion knitwear designers.

The researcher identified that the deliberate instigation and application of unusual combinations of pre-registered and new garment templates, garment design details, motifs, patterns, knit structures, design tools, design methods, and machine settings creates a significant extension of the high-fashion creative envelope of the computerized seamless V-bed knitwear technology. This creative envelope becomes appropriate to high-fashion knitwear design by being sufficiently larger and more diverse than the 'routine' working envelope of computerized seamless V-bed knitting technology as in its intended role of creating retail mass-market knitwear. The limiting factor is technological: not all of the combinations can be knitted. Substantial trial and error investigation in adjusting garment construction details and knitting machine settings are often needed to ensure knit-ability or identify that a particular combination is 'un-knittable'.

Design method: Trial and error

The deliberate use and conscious use of 'trial and error' experimentation emerged as perhaps the most powerful high-fashion design method identified in this research for use with computerized seamless V-bed knitwear. There are three reasons in this particular design and manufacturing context why 'trial and error' is significant as a design method. Firstly, on the creative side, when creating unusual and extreme garment shapes, the garment shapes and silhouettes that are knitted are often different from that expected or intended due to a wide variety of effects relating to multiple highly interacting factors including: stitch structure patterns, garment shapes, wearer's body shapes, sizing, yarn characteristics and knitting machine settings. In parallel, unusually aesthetically good outcomes can sometimes emerge unexpectedly from small changes.

Secondly, on the manufacturing side, many garment designs that should in theory be possible to knit cannot be produced. The computerized seamless V-bed knitting technology has fuzzy and multi-factorially complex limits. There are a wide variety of knit failure errors that include missed stitches and garment holes (see Figure 65 below) pattern errors, broken needles, software failure and hardware failure. In the limit, there is potential for substantial physical destruction of the knitting machinery.

Figure 65: An example of a knit error

Third, resolving knitting errors can involve changes to the garment, changes to how that garment is programmed or changes to the knitting machine settings. These changes in turn may affect garment shape, drape and silhouette and fabric feel and appearance which may in turn require further modifications to return the garment to that intended by the designer. Many of the above physical knitting errors can be overcome by careful experimentation with the several dozen adjustment factors. In the course of correcting the knit errors through 'trial and error', new design possibilities often emerge (see, for example, Figure 66).

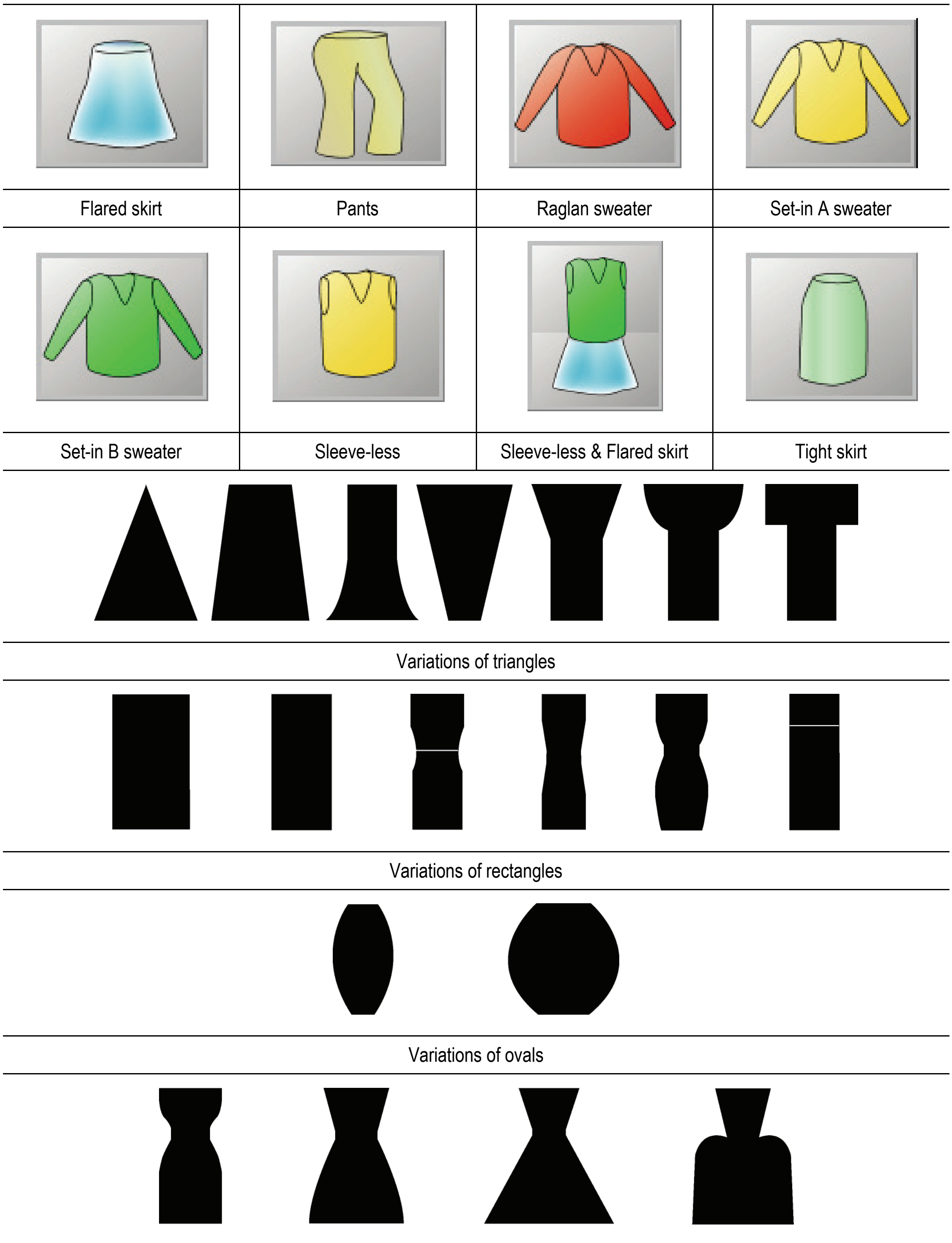
Figure 66: An example of accidental artistic effects emerging during the process of repairing knit errors

The 'trial and error' design method can be applied as a strategic element in all knitwear design methods. The effect is to further extend the envelope of potential high-fashion design opportunities and indentify increasing potential for high-fashion design using computerized seamless V-bed knitting technology in ways that can be exploited by knitwear designers.

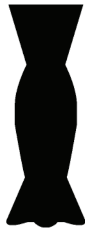
Design method: Silhouette design

Designing and creating garment to result in an intended silhouette is an essential aspect of high-fashion design. Typical standard fashion design silhouettes are shown in Appendix 6.

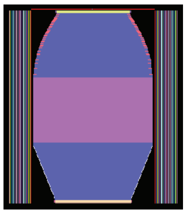
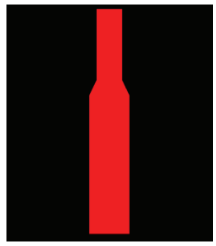
The silhouettes of high-fashion knitwear designs are often extreme. Creating high-fashion designs using a computerized seamless V-bed knitting technology requires the designer to be able to identify how to create intended silhouettes within the design performance envelope of the technology and also to be able to design garments that can be knitted without error and without breaking the knitting machine. Examples of forty-nine (49) base garment shapes that were used to make a variety of the silhouettes of high-fashion knitted garments during the research are shown in Figure 67 below.

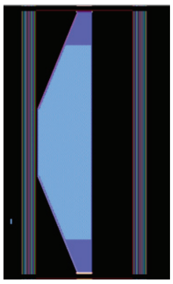
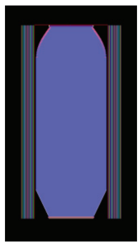
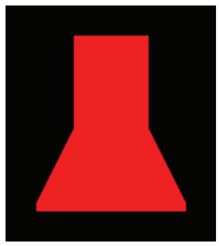
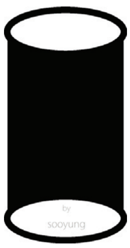
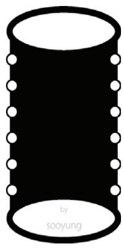
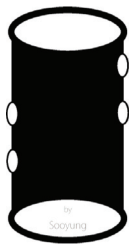
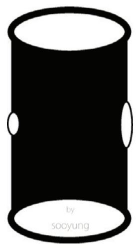
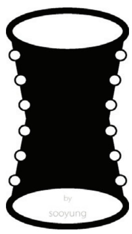
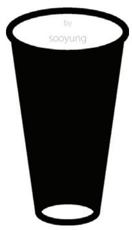
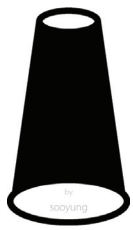


Variations of X-forms

Hybrids

		
Barrel shape	Hour-glass shape	Ice wine bottle shape

			
Hexagon	Octagon	Range-hood shape 1	Range-hood shape 2
			
Cylinder	Cylinder with small holes	Cylinder with 4 medium holes	Cylinder with 2 asymmetric holes
			
Hourglass	Hourglass with small holes	Wedge	Triangle

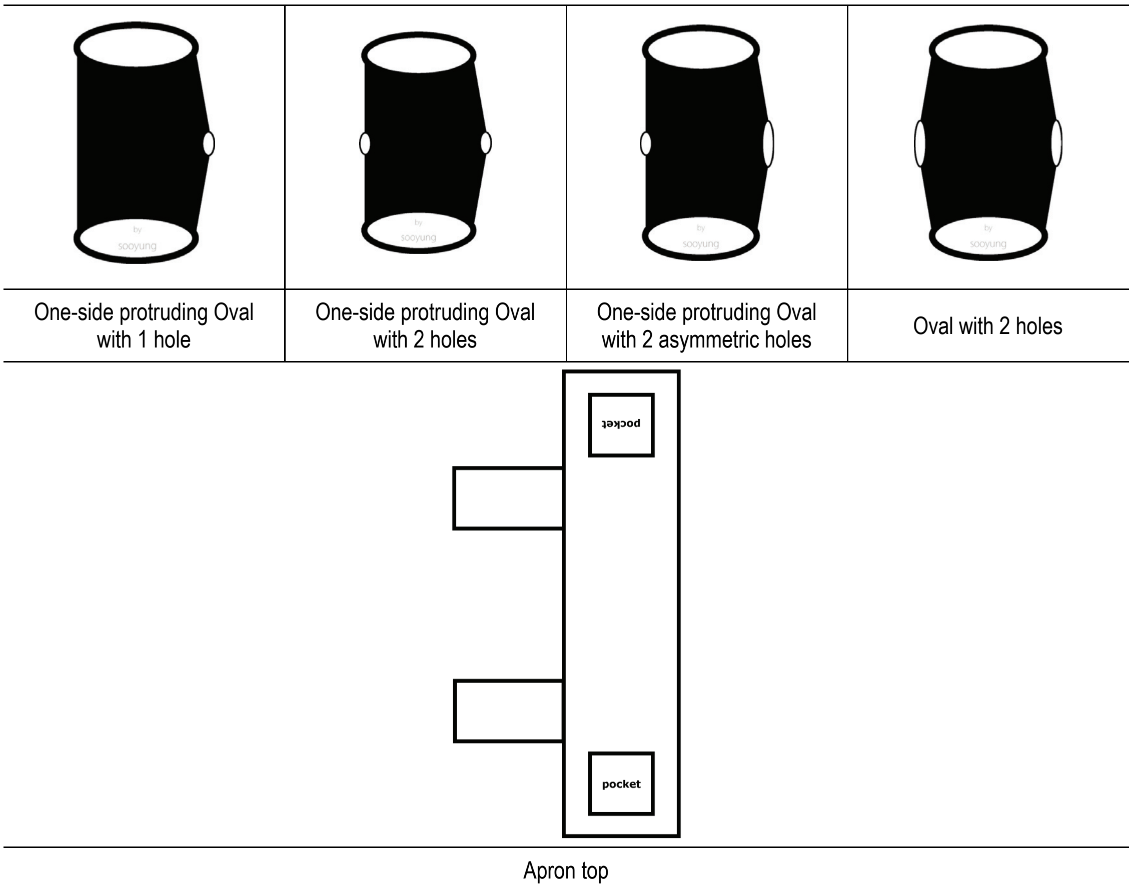


Figure 67: Examples of silhouettes of garments created during the research

These images demonstrate that the design methods and new integrated workflow process developed as a result of this research can be used to create high-fashion garments without dependence on knitting machine technicians.

The research identified, however, a significant problem in creating a design method to create garment designs with particular silhouettes. The problem is the difficulty of predicting silhouettes at the design stage. The context of high-fashion knitwear makes silhouette prediction more difficult than for retail mass-market knitwear garments.

The silhouette of a knitted garment depends on multiple factors such as the garment shape and its drape. Knitwear is highly elastic and has drape properties that themselves depend on multiple factors. The silhouette and fit of a knitted garment can change dramatically depending on the build and stance of the person wearing it and how the garment is arranged on them. The two images in Figure 68 show the same garment having two different silhouettes and appearance when worn by two models of almost identical build, but slightly different height.

Figure 68: Examples of different silhouettes of the same garment on two different models. Source: (DAFWA, 2007)

The explorations made possible by the researcher having direct access to and control of computerized seamless V-bed knitting technology showed there is much still to explore in relation to silhouette shaping in high-fashion knitwear using this technology. The finding in this case is the need for further research in creating design methods for silhouette shaping. Opportunities exist in research undertaking of relationships between designed garments and intended silhouettes by using new technology such as body scanners.

Training

The researcher attended three formal training periods of 9 weeks in total. The researcher's first training at Shima Seiki covered both basic knit programming and the design side of the computerized seamless V-bed CAD system. The second and third trainings focused primarily on knit programming. In both these training periods, the researcher had two roles: the first as a fashion designer training to be able to use the technology. The second as a researcher, a participant-observer, watching and self-reflecting on the training, the learning processes, and the design and manufacture workflow processes.

From the perspective of the PhD research, the focus and findings from each training differed. During the first training, the researcher found many weaknesses of the formal training for high-fashion knitwear design. In the second training, the researcher focused on one particular issue: the different aspects of the dependence of the high-fashion knitwear designer on the knitting machine technician. In the third training, the research focused on identifying how the knitwear designer might undertake more of the technician and knitting machine operator roles in the earlier design phases of the workflow process. As a side issue, the researcher also identified the importance in training situations of a particularly intensive way of note taking typical of fashion designers.

Teaching

A crucial question of the new integrated high-fashion knitwear design and manufacture workflow described above is whether it can be taught, and learned by, fashion design professionals. Obviously, it is possible to learn this new approach because the researcher herself learned to the standard to create professional high-fashion designs to the point of *1st sample* using this technology. In doing this, the researcher has also applied and tested the new integrated high-fashion knitwear design process workflow for computerized seamless V-bed design and manufacture. The example of the researcher is unusual. The researcher is highly experienced in fashion design and highly motivated to learn. Her example is unusual also due to her particular mix of previous experience and her opportunity to acquire new skills that include technician and knitting machine operator's knowledge via training in courses at Shima Seiki in Japan.

The real test is whether conventional fashion design students and contemporary high-fashion designers can be taught to use the computerized seamless V-bed knitting technology as part of their design development in a way that circumvents the problems identified in Chapter 3 that are also addressed by the other findings of this PhD research.

The 'teach-ability' of the proposed new approach, design methods and design process workflow for computerized seamless V-bed knitwear design has been explored in this research by the researcher delivering seminars and demonstrations, and tutoring fashion design students undertaking projects using the computerized seamless V-bed knitting technology. Preliminary findings from these activities are promising. They suggest:

- Interested fashion students with sufficient time and access to the technology appear to be able to progress easily to using the new approach;

- Changes to fashion design curricula are necessary to provide sufficient hands-on time and experience for students; and
- In the short-term at least there appears to be a significant role for a designer-interpreter: a high-fashion designer with skills in using the computerized seamless V-bed knitting technology to collaborate with other fashion designers to facilitate them developing and testing designs.

CHAPTER 8: Findings: High-fashion Design Methods that Extend the Creative Performance Envelope

The preceding chapter provided an overview of the findings and detailed information about the new integrated computerized high-fashion knitwear design and manufacturing process identified in this research in which high-fashion knitwear designer takes full control of the design and production process using the computerized seamless V-bed knitwear design and knitting system up to and including the successful creation of the *1st sample* garment.

Enabling the knitwear designer to function as a designer in the computerized seamless V-bed knitwear system required identifying and creating ways that the existing facilities of the computerized seamless V-bed knitwear design and manufacturing system were repurposed to extend the functional envelope of the system to offer the creative opportunities and potential needed for high-fashion.

This chapter focuses on the research findings relating to the high-fashion design methods that were developed to extend the performance envelope of the computerized seamless V-bed knitting socio-technical system to enable knitwear designers to extend the use of this socio-technical system for high-fashion knitwear design as well as the role intended by the manufacturer as a knitwear manufacturing system that requires minimal design expertise.

Extending the performance envelope of the computerized seamless V-bed knitting socio-technology system required design methods that:

- Increase the role of, and access to creative benefits from, knitwear designers;
- Enable the creation of non-routine knitted shapes, garments, fabrics, surface interests and knit structures; and
- Knitwear designers without technical expertise can easily use these methods.

Obviously, this task can be undertaken at various conceptual and technological levels and in various ways. For example, the approach might be different if there was access to active participation by the computerized seamless V-bed knitting system manufacturers. In this case, however, the technology of the system being used for the research was fixed: a Shima Seiki SDS-ONE® system. The research challenge then was how to identify ways of modifying and repurposing for high-fashion knitwear design the existing knitwear design and manufacturing processes that were intended primarily for manufacture of simple shaped mass-market knitwear.

Seven classes of new high-fashion design methods

Seven classes of new design methods were developed in the research that fulfilled all three of these roles of extending the high-fashion design envelope of computerized seamless V-bed knitting system whilst providing non-technical knitwear designers with easy use of these methods. The design methods were identified on the basis of extensive exploration by the researcher in undertaking the projects. They in part exploit the reality that whilst the knitting technology presents a relatively simplistic interface for the production of routine mass-market garments, the technology also provides ways of accessing the underlying functioning via highly technical programming interfaces for use by engineering-trained knitting machine technicians. The challenge was to identify less technical ways of fundamental functions of the knitting machine that are of use in high-fashion knitwear design.

The research developed one strategy that opened up the path to multiple new design methods. This was the development of two additional ‘generic’ and highly modifiable garment templates that when combined with elements of routine pre-registered garment shapes, and with each other significantly extend the creative opportunities for high-fashion garment design using the system.

Other new knitwear design methods developed during the research exploit repurposing of software tools of the knitwear system to exploit the creative combinatorics potential of using the system to ‘attach’ different and modified parts of garments in a variety of ways to create unusual outcomes. It would be expected that similar design methods would apply to other manufacturers of this computerized knitting technology.

The seven classes of design methods developed in this research are:

1. Extreme use of existing tools to modify routine pre-registered computerized garment templates to creatively extend the appearance of the routine garments into the realm of high-fashion.

2. The use of garment shaping via arrangement of knit stitch patterns.

3. The repurposing of the S•Paint software to produce extreme garment modifications.
4. The use of new multiple highly configurable types of ‘tube’ garment templates that include slashes and slits developed during this research.
5. The use of new multiple highly configurable types of two dimensional flat panel garment pattern developed during this research.
6. The use of S•Paint and other tools to ‘attach’ parts of modified garment shapes to produce creative outcomes.
7. The deliberate application of ‘trial and error’ methods to forcefully extend the performance envelope of the knitwear system.

These are described in more detail below.

Design Method 1: Extreme modifications to pre-registered garment shapes

Existing pre-registered garment shapes for the seamless V-bed knitting technology are intended to produce routine garments with simple details and fabric with relatively conservative, repeated patterns. They can be adjusted in-line with conventional mass-market design changes such as a change in decorative pattern on a sweater, adjustments to the ribbing on a cuff or hem, adjustments to sizing, or different stitch and color patterns on a fabric. The seamless knitwear design and manufacturing system includes a relatively wide range of pre-registered computerized garment templates for this purpose.

The most straightforward way of extending the boundary of the performance envelope of the computerized seamless V-bed knitwear design and manufacturing system is to creatively explore extreme modifications to the existing pre-registered patterns to achieve outcomes more in line with high-fashion expectations and conventions. This approach was used at different points in several of the projects undertaken in this research in a variety of ways. As discussed in Chapter 8, these varied from extreme modifications in e.g. the AltaRomAltaModa pieces, to the almost negligible modifications in the Wagin Woolorama 2007 Ambassador’s outfits. Examples of pre-registered garment shapes that were found to be amenable to this design method are shown in Figure 69 below.

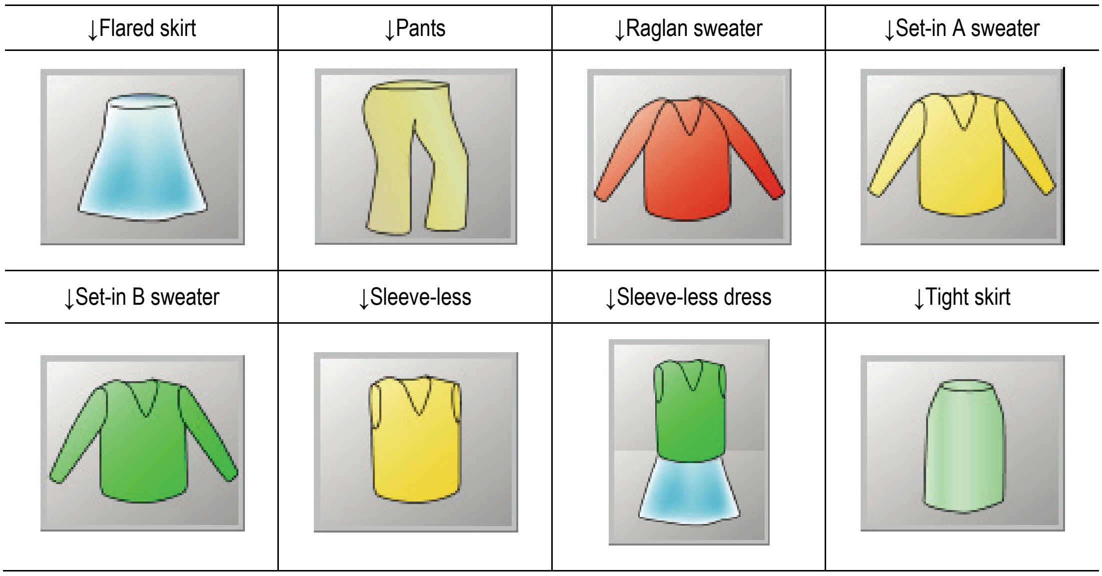


Figure 69– Examples of pre-registered garment shapes that can be developed into conservative high-fashion garments by high levels of modification of original template

Design method 2: Garment shaping using knit stitch patterns

It is possible highly modify the shape and silhouette of garments to elide them into the high-fashion arena by using patterns of knit structure to create a wide variety of different garment silhouettes, shapes, drapes and fits. The design approach involves using different areas of a garment with different knitting needle movements (e.g. knit, tuck, float, and combination of these movements) to modify the shape and stretch of a garment. The effect occurs because different knit structures occupy different space and have different physical properties. This design approach can be used creatively in high-fashion knitwear to significantly modify the 'as worn' shape of a garment that is otherwise more conventional.

This design method can be easily implemented with the existing tools of the computerized seamless V-bed knitwear system. It aligns well with the aims of the research in that it extends the high-fashion performance envelope without requiring changes to the design and manufacturing system and without requiring technical skills on the part of the knitwear designer.

The researcher investigated in detail this high-fashion knitwear technique in her Masters Research into fixed needle-count knitting (Yang, 2007). Knitted garments were shaped by using three bands of different stitches with the number of stitches per row held constant (except of course in the arm and neck area. Figure 70 below shows some examples of the use of this approach and how the three bands of different stitches result in completely different garment shapes and silhouettes.

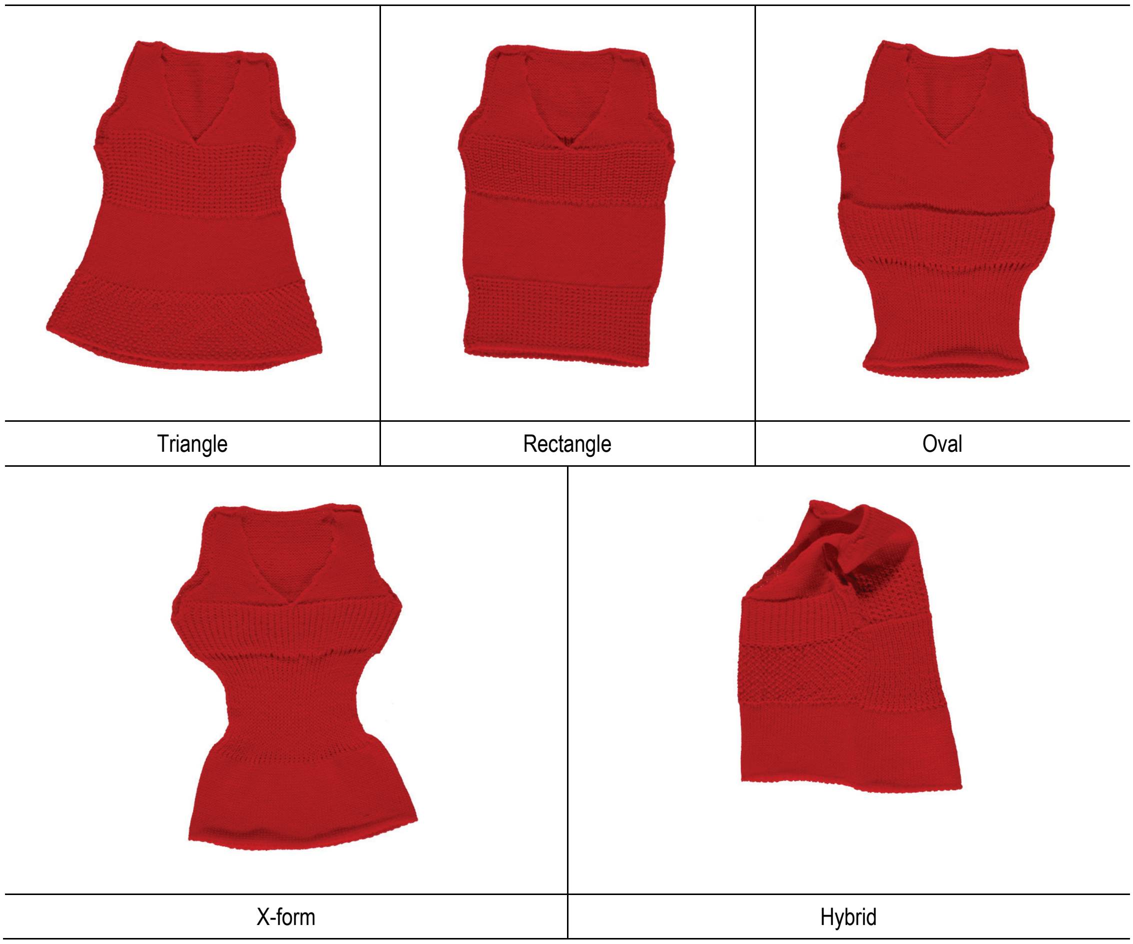


Figure 70: Examples of high-fashion garment shaping via knit structure

Design method 3: Extreme use of S•Paint

As another design method, the researcher focused on a secondary attributes of the knitting system's S•Paint software to enable the knitting system user to create new geometric shapes or to combine the shapes to form fabric/garment shapes. S•Paint images comprise data created in the S•Paint software and registered into the data for each garment part is the description such as *front body*, *back body*, and *sleeve* and these are displayed on the S•Paint screen (see Figure 71 below).

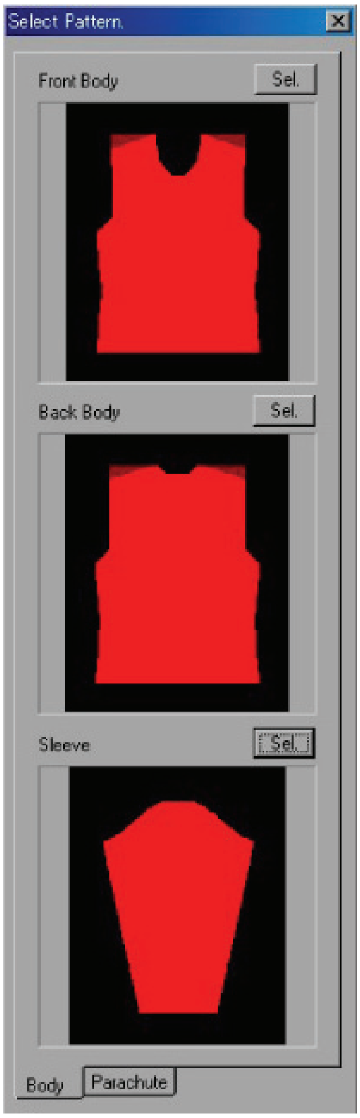
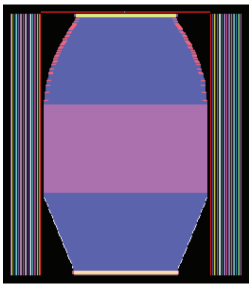
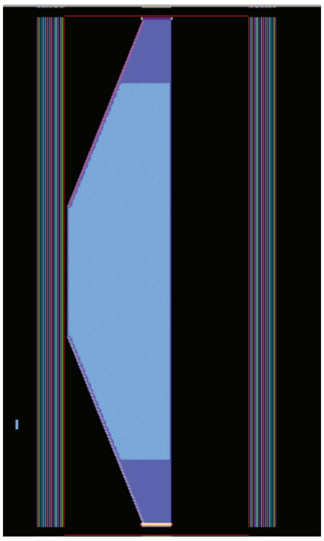
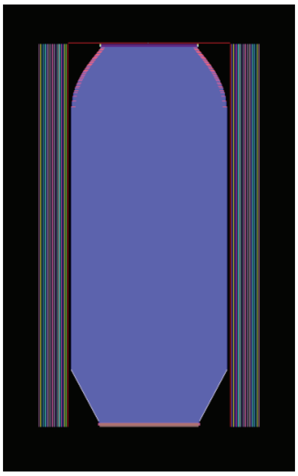


Figure 71: Example of garment parts registered on the S•Paint screen. Source: (Shima Seiki Mfg., 2008d)

The researcher discovered during the course of undertaking projects in this research that the S•Paint software in the SDS-ONE® CAD system can be also used to create unconventional garment shapes by heavily 'incorporating' geometric shapes and 'attaching' them together using pre-registered garment shapes to create other garment shapes. This is an extreme but effective use of this S•Paint design software which is more normally used as one of the starting points to create a fabric or garment piece. Examples of high-fashion fabrics and garment shapes that have been developed via S•Paint images are shown in Figure 72 below.

	
Barrel shape	
	
Hour-glass shape	Ice wine bottle shape
	
Hexagon	Octagon

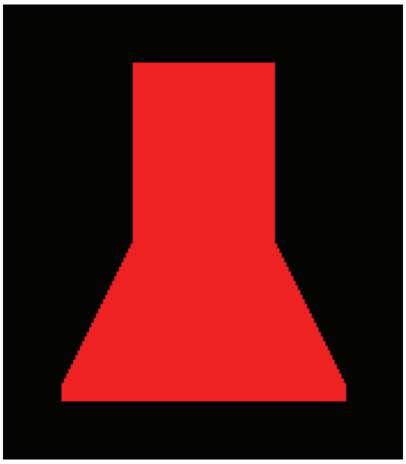
	
Range-hood shape 1	Range-hood shape 2

Figure 72: High-fashion garment shapes using S•Paint

Design method 4: The use of new configurable 'tube' garment templates with slashes and slits

The researcher explored garment shape 'primitives' that could be used either alone or in combination with parts of the pre-registered garment shape suite to create high-fashion garment shapes. She identified a simple knit structure comprising a tube with options for slashes and slits that could be used in a very large number of different ways. At her request, a Shima Seiki technician programmed the additional patterns as a variety of templates. The dimensions, proportions, and knit structures, of the tubes and their slashes and slits can be radically changed resulting in a large number of differently configured tube shapes that can be used as different kinds of garments in a wide variety of arrangement (Figure 73).

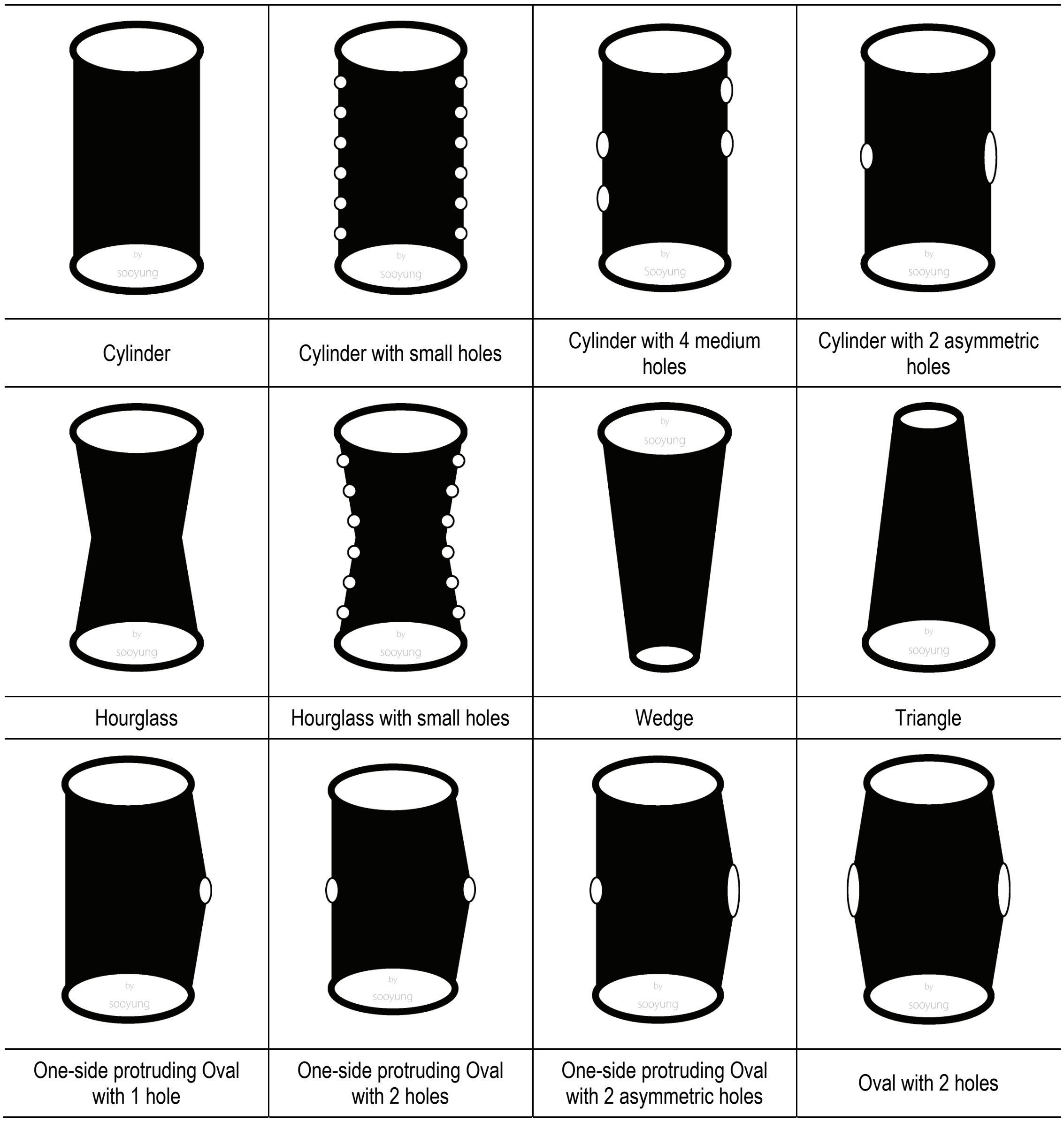


Figure 73: Examples of the ‘tube’, slash and slit garment templates

As a design method for extending the performance envelope of the design and manufacturing output of computerized seamless V-bed knit design and manufacture this new geometric template design method was unusually successful and later provided the basis for the training programs for fashion designers described in the following chapter. Examples of high-fashion outcomes of the use of this ‘tube’, slash and slit design approach are shown below in Figure 74.

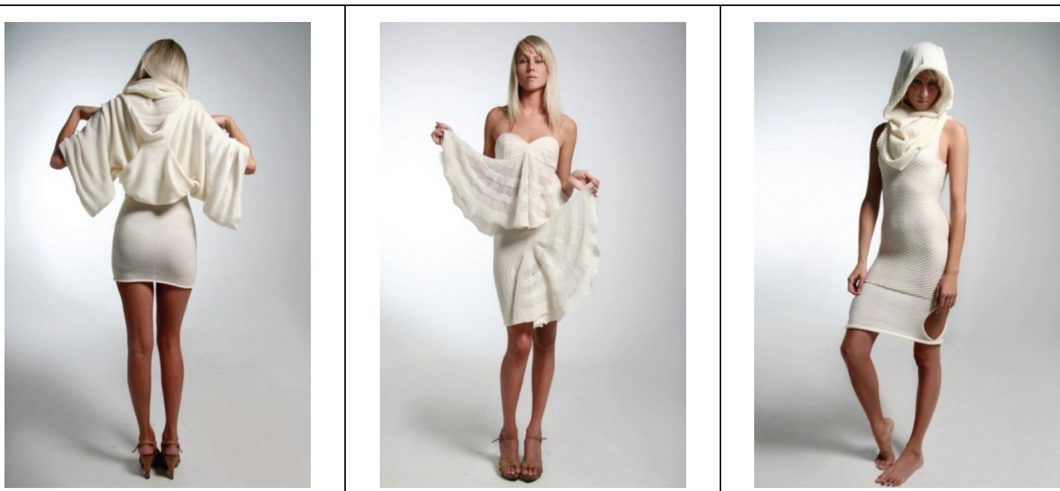


Figure 74: Examples of the use of the ‘tube’, slash and slit garment structure. Source: (DAFWA, 2007)

Design method 5: The use of new configurable ‘tube’ flat panel garment template

The ‘tube’ garment templates with slashes and slits offered a three dimensional knitted garment shape. In parallel, the researcher devised and trialed a simple highly configurable two dimensional garment template. This was based on a simple apron with pockets. The proportions of this new 2D garment template are highly and it can be combined with other for combinations with other garment shapes in a wide variety of garments from hats to trousers. It provided another opportunity for significantly extending the high-fashion creative performance envelope of computerized seamless V-bed knitting systems in ways that could be easily adopted by fashion designers. Again at the researchers request this template was programmed by a Shima Seiki technician in Japan. The pattern topology is simple (see Figure 75 below).

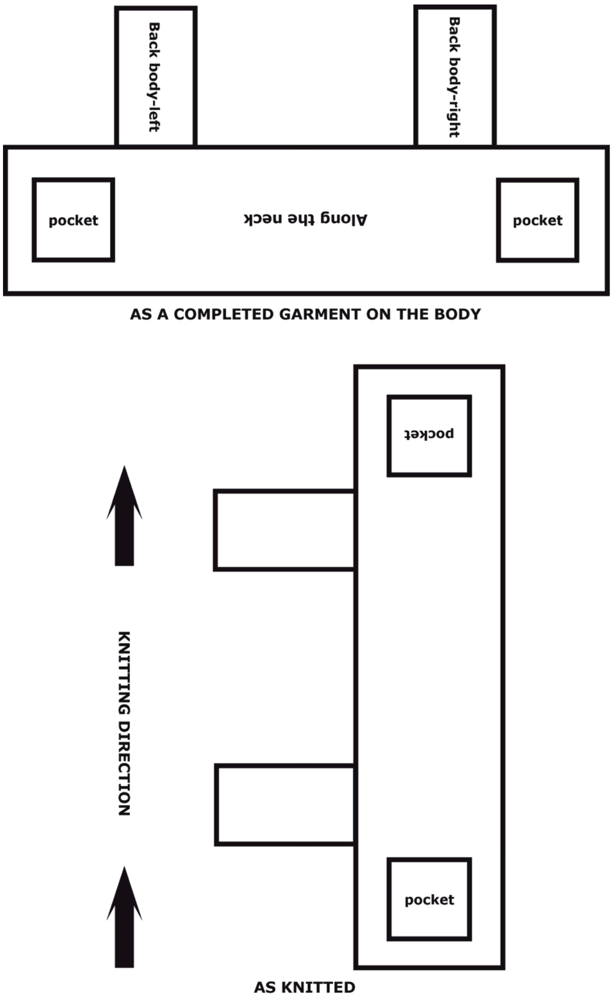


Figure 75: Two dimensional flat panel garment template.

The benefits of this 2D design method are that it can be dramatically shaped in a flexible manner to have different clothing roles. It can be 'attached' in the computerized design phase to other garment elements in a variety of ways, and it can be further shaped and structured by appropriate choices of knit structures. An example of garments created using this flat 2D pattern is shown in Figure 76 below.

Figure 76: A *1st sample* of 'apron-based' evening wear using the flat 2D garment template

Use of the template is shown in Figure 77 below.

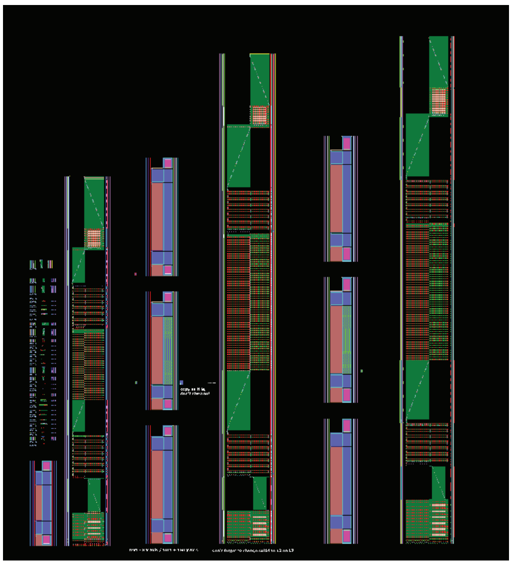


Figure 77: Examples of high-fashion garments using the flat panel template.

Design method 6: Combining garment parts and design methods

An additional design method of ready use in high-fashion garment design involves combining the above five design methods and the products of them in ways that offer creative opportunities over and beyond the possibilities of any individual method. Many of the examples illustrated above also have used utilize combinations of the above approaches. Examples are shown in Figure 78.

Figure 78: Examples of fabrics and garments using combinations of design methods. Source: (DAFWA, 2009)

Simple mathematical approaches such as Combinatorics, can be applied to extending the mapping or envelope of design solution space for creating high-fashion knitwear. Forty-nine (49) base garment shapes were used in different combinations in this research. Complexity arises from this increased envelope of possibilities for high-fashion design. To design a sweater, a knitwear designer needs to identify and choose a number of design possibilities. In terms of garment silhouette, the designer must combine at least five design features: neck design, shoulder line, body shape, sleeve design, and edge. Additional features such as pockets and embellishments are optional. Using fundamental counting principles, a single sweater design requires one neck design, one shoulder line, one body shape, one sleeve design, and one edge. This, in Combinatorics sweater design, is a combination of 1 (1x1x1x1x1=1). If the designer takes into account of two style options for each design feature, the options create a total number of thirty-two possible sweater designs (2x2x2x2x2=32). If the designer does the same with forty-nine style options for each design feature, then these options result in the total number of possible sweater designs increasing to 'two hundred eighty two million four hundred seventy five thousand two hundred forty nine' possible combinations (49x49x49x49x49=282,475,249).

Design method 7: Deliberate use of 'trial and error'

Through analysis of their reflective comments in their work diary and through reflections on their experiences in the eight projects, the researcher realized that one of the most effective design methods for extending the high-fashion performance envelope of the computerized seamless knitting technology was the deliberate use of 'trial and error'. This approach has at least three aspects. First, it can result in unexpected solutions that open up new possibilities for using the technology in high-fashion. An example is the fabric shown below in Figure 79 which was developed whilst using trial and error to address a different issue.

Figure 79: Outcome of trial and error. Source: (DAFWA, 2006)

Second, the deliberate use of 'trial and error' methods emerged in the research as an effective way to explore the boundaries and extend the reach and creative potential of other design methods. In computerized seamless V-bed knitting, there are irregular technological boundaries that limit knitting possibilities, often in unexpected ways. Extending the creative envelope of the technology requires not only findings ways of designing high-fashion garment using the computerized seamless V-bed knitting software, it also requires this creative performance envelope also including the designs that the computerized seamless V-bed knitting is physically able to knit. This is a significant issue. Many garment designs that should in theory be possible to knit cannot be produced. The technology has fuzzy and complex limits. There are a wide variety of knit errors ranging that include missed stitches, garment holes, pattern errors, broken needles, software failure and hardware failure to the potential for complete physical destruction of the knitting machine.

This latter issue is almost certainly one of the key drivers that have shaped how the manufacturers of computerized seamless V-bed knitwear technology have defined the workflow and design processes such that they exclude intervention by high-fashion designers and highly creative 'unusual' designs and instead have reduced design mainly to selection between well-tested simple garments. Deliberate use of 'trial and error' methods helps build up a body of knowledge about design strategies and methods for using this new technology to produce unusual and complex high-fashion garments.

From experience in the research, whilst a designer is developing a new high-fashion garment, many of the issues come to head. Knit errors emerge unexpectedly in even the most innocuous garment styles (see, for example, Figure 80).

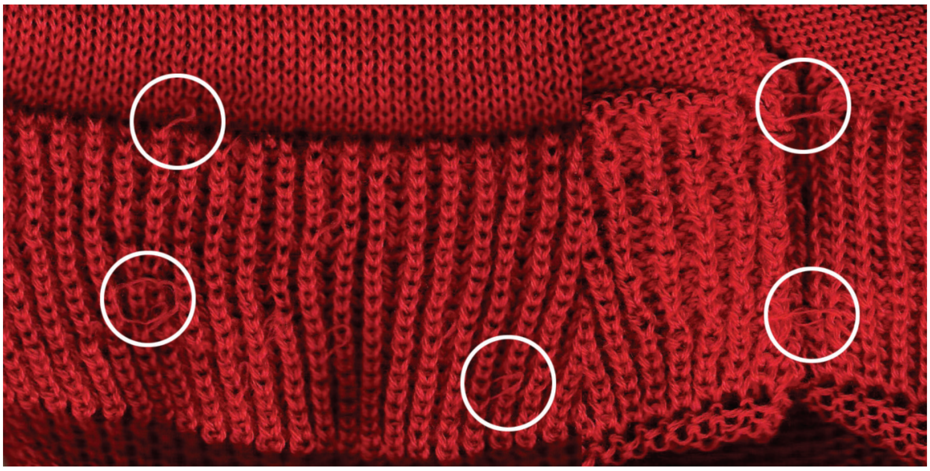


Figure 80: Example of knit errors

The kinds of knit errors shown above can result from, and often be resolved by, very small changes to the knit data, via the design software and the knitting machine setup data. Many of these knit error situations do not respond directly to analysis (unless they involve major errors of programming). From experience, as a design method, the deliberate thoughtful and careful use of 'trial and error' is very effective in this particular design and technology environment. Many physical knitting errors can be overcome by careful experimentation with the several dozen adjustment factors that influence them.

Knitting program code faults primarily appear when prototypes are knitted in the stage before *1st sample*. These faults can be due to factors at different parts of the design process and the integrated nature of the design process means they can be readily resolved by the knitwear designer. Also, in the course of using 'trial and error' as a design method, new design possibilities emerge and the envelope of potential high-fashion use of the technology is extended.

CHAPTER 9: Findings: Computerized Seamless V-bed Knitwear System Software Interface

As discussed earlier, computerized seamless V-bed knitting systems and their interfaces target two distinct user groups:

- Fashion designers creating good quality routine retail mass-market knitted garments; and
- Engineering technicians programming the knitting machine by manipulating the machine functions directly.

The working envelope of the computerized seamless V-bed knitwear technology is highly restricted for the first group of users, fashion designers and focuses on the use of pre-registered garment shapes and patterns. Through these pre-registered standard garment shapes it provides good cover of all the major conventional retail knitwear garments types, and the software interface provides an easy and quick way for fashion designers to create good quality retail knitwear.

In contrast, there are also much more complex and technical pathways in the computerized seamless V-bed knitting software that fashion designers do not use. These parts of the software are for use by knitting machine engineers and technicians to create new garment templates and pattern development packages, as well as programming the operation of the knitting machine more directly. For knitting machine engineers and technicians, the working envelope of the knitting technology is very much larger than that available to fashion designers.

High-fashion knitwear designers need a larger creative working envelope of the computerized seamless V-bed knitting system – similar to that available to the knitting machine engineers and much larger than the working envelope available to knitwear designers. High-fashion knitwear designers, however, do not have the technical skills and training of the knitting machine engineers and instead requires an interface with high usability that aligns with traditional high-fashion design skills and ways of working.

This research was undertaken using the Shima Seiki SDS-ONE® software. The Shima Seiki knitting system is one of the greatest technical improvements in knitting technologies, especially for simple conventional garments. However, it is a different story when designing novel textiles or garments. From the researcher's point of view, acting as a high-fashion knitwear designer, the software interface is poor in usability for a high-fashion knitwear designer because it is built to dictate a user to follow a strict sequence to complete a task or requires high level technical skills. The high-fashion user trying to operate the software in ways necessary to create high-fashion garments is often blocked by the software. In some cases, this may be because the software has been developed to protect the knitting machine from harm. In other cases, however, it appears that this is a local sub-optimization issue due simply to the software being optimized for creating retail garments with minimum variations as fast and easily as possible.

The research suggests there is an opportunity for an improved software environment for high-fashion knitwear design involving the creation of more extreme and unusual fabrics and garments alongside the current software paths for retail knitwear design and direct engineering programming of the knit process.

The experiences of the researcher in undertaking the eight semi-commercial knitwear projects, success of the new integrated high-fashion knitwear design process and teaching others to use the computerized seamless V-bed knitwear technology are that this might easily use the same underlying functionality of the knitwear design and production system. Its suggests that all that is required is a user interface and workflow process at the individual and group levels more suited to high-fashion knitwear design and manufacture to and including the knitting of the *1st sample*.

In many cases, the conventional retail knitwear design software available within the computerized seamless V-bed knitting system could also do with increased attention to improving its usability and reducing unnecessary steps in the process. The following example, describes the most basic knitted garment design in the Shima Seiki WholeGarment® system.

Example: designing and knitting a raglan sweater

Creating the design and knitting a WholeGarment® raglan sweater is the first topic a trainee on the Shima Seiki training program in Japan encounters when learning how to create a WholeGarment® on the knitting system. The programming and virtual knitting process is shown below in Table 11.

Table 11: The steps in creating a WholeGarment® raglan sweater

Steps in order	SDS-ONE® CAD Software in use	Processing time required (minutes)
File: on main menu bar New window Picture Directory Gauge Input Information Size Input Information Edit Pattern of Narrowing (AH: Front) Edit Pattern of Narrowing (AH: Back) Edit Pattern of Narrowing (AH: Sleeve) Initialize & Outline Adjust Doubling Set Slide Process S•Paint blinking Warning Now Saving Confirm Processing Package Development: Partition Order Draw Processing Package Development: Package Development Processing Package Development: Package Pat. Gather Up Processing Package Development: Package Order Draw Automatic Software Settings Area Auto Process Parameters	*KnitPaint*	2

Processing Output Data Knit Simulations>Simulation Start >Loop Simulation Simulation Start>No Error Found		
Loop Simulation window		
Making the Connecting Information Knit Loop Simulator Now Loading File	Transition occurs from *KnitPaint* to *Design*	2
Loop Draw Yarn Setup Processing	*Design*	1
Loop Draw End Make Shadow		1
	Time required in total	**6**

Applying basic usability analysis indicates that there is potential for the usability to be improved. Some information and warning message windows appear to be superfluous and from a fashion designer's point of view the ways that the windows pop up is distracting as they appear randomly rather than at the same spot on the screen. It also appears that, from a fashion designer's point of view the process can be simplified.

Problematically, the process is sequential and tightly linked from one step to another. This is advantageous in terms of users needing very little skills to produce simple retail garments because all that has to be done is simply to follow the sequence. For those designing more unusual or extreme fabrics and garments who wish to heavily modify the output, this rigid process is problematic. To make changes one needs to return each time to the beginning of the process and work through it each time.

Interface and knitwear design technical constraints

This research was undertaken remotely from technical advice and assistance. The researcher's Shima Seiki tutors in Japan strongly advised taking care to avoid going too near the limits of the knitting machine to avoid unnecessary technical problems. The knitting machine limits are however neither obvious nor simple. For example, while applying stitch patterns on fabrics or complex shaped garments, this results in a recommendation to only apply stitch patterns to areas with straight edges. In addition, even on areas of a garment with straight edges, the researcher was advised to leave at least two courses as 'no texture-plain' on both left and right sides. Similarly, two rows at both top and bottom were also to be kept plain. This can be seen in Figure 81.

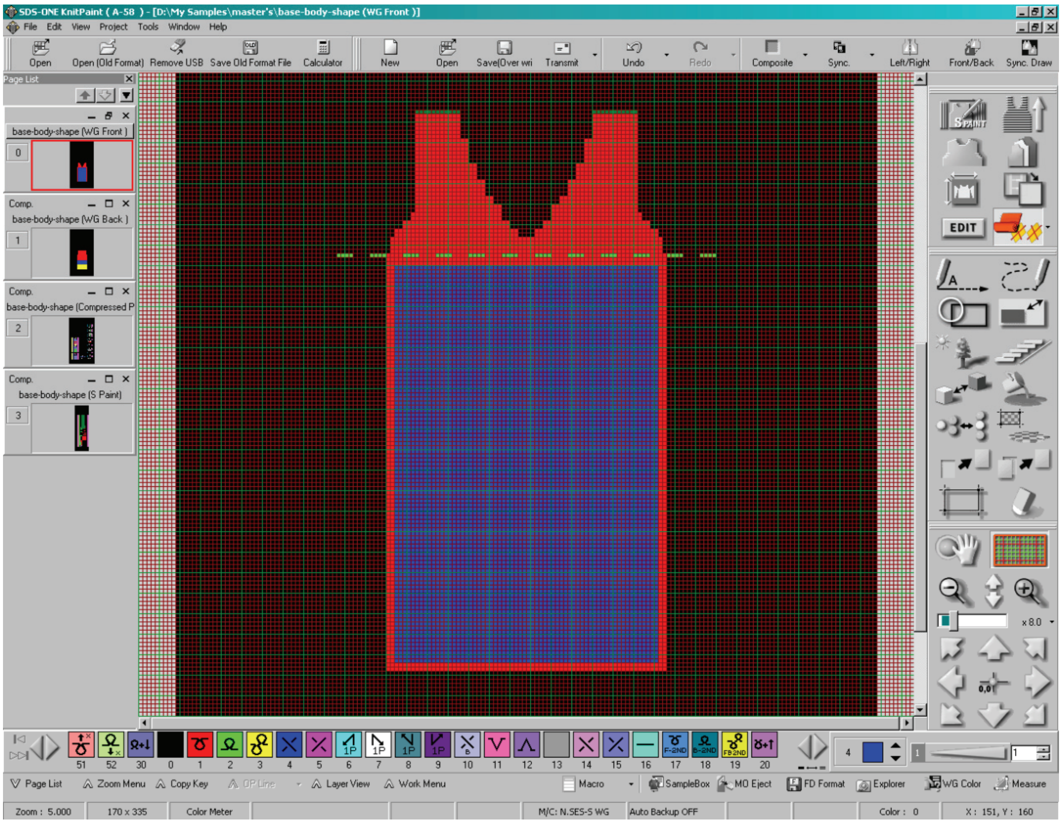


Figure 81: The created knitwear design technical constraint

In other words, stitch patterns can be applied only to the straight edged parts of the sleeveless top and a thin 2 stitch ‘frame’ must be all around (the blue area shown in Figure 82). Design details such as ‘textured from below bust’, ‘textured from below darts’, and ‘patterned except specific part’ can be regarded as ‘safe’ (see Table 47 in Appendix 5). This safe conduct, however, leaves a thin line between the stitch pattern repetitions, resulted in interrupted unmatched stitch patterns.

From the experiences of pushing the boundaries of the creative envelope possible with the computerized seamless V-bed knitting technology, it became clear that this ‘safety guideline’ and many other similar technical constraints were less critical to follow, but rather something to take into account when resolving knit-ability problems.

Visual appearance of the software interface: cultural and style issues

From experience of using *KnitPaint* software, and especially the S•Paint software that is more the province of knitting machine technicians, it was clear that the visual appearance of the interface that is the basis of programming the Shima Seiki WholeGarment® knitting system needs to be more designer-friendly if the manufacturer is considering accommodating those designing more complex and unusual fabrics and garments. Offering a few available color schemes of software would help. The ‘black screen’ of the ‘Control Simulation window’ displays the action of each knitting needle and the position of each yarn carrier. From the perspective of a fashion designer, the look of the window is unnecessarily technical, masculine and dominant (Figure 82).

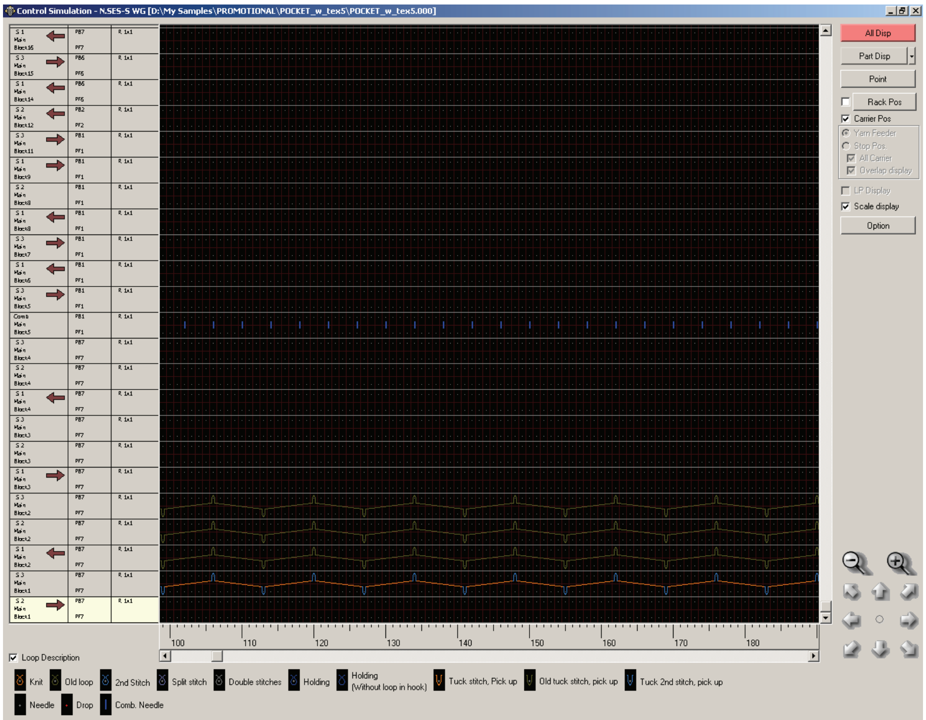


Figure 82: Screen shot of Control Simulation window

The 'Control Simulation window' is needed to check everything before starting knitting. From experience across the period of research, it is clear that the hard and daunting appearance of this window results in users trying to avoid it. This means that one of the most efficient and frequently used functions of the software is inhibited by its appearance and suggests that this could easily be remedied by revising the interface design to improve usability

Making changes to the appearance and functioning of *KnitPaint* to create a more user-friendly sketch-like environment would, in turn, help fashion knitwear designers to maintain their visual thinking and creativity while creating both garments and knit data. For example, having a white screen with the option to turn the grid line on and off would help some designers. The fixed on-screen grid line is distracting and enabling its removal would help to provide the knitwear designers with the feeling they are working on the sketch paper. This is confirmed by the discussion of improvements to on-line sketching environments are described by Lim, Qin, Prieto, Wright and Shackleton (2004, p. 395).

CHAPTER 10: Findings: High-fashion Knitwear Design Projects Using Computerized Seamless V-bed Knitting Machine

This chapter describes in detail the findings from four projects undertaken during this research. In addition, the chapter also describes the researcher's reflective analysis on her experiences in designing and producing high-fashion glamorous knitted evening wear using the Shima Seiki WholeGarment® computerized seamless V-bed knitting system. The five sections are:

- Garments for the 'Design for Comfort' wool promotion high-fashion design project (with five Western Australian fashion designers);
- Garments for the 'Wagin Woolorama Ambassador 2007';
- Collaboratively produced garments using Merino Soul's yarn (with designer Bianca Gervasio);
- Extreme size knitted cone-shaped Art artifact; and
- Reflections on the use of the computerized knitting system for the design of glamorous outfits.

'Design for Comfort'

The 'Design for Comfort' fashion design project involved using the Shima Seiki WholeGarment® knitting machine at the Department of Agriculture and Food Western Australia (DAFWA) to create customized high-fashion knitted fabrics from which five Western Australian designers created dramatic garments for a fashion show and exhibition using 'cut and sew' approaches. The aim of the 'Design for Comfort' project was to create attractive knitted garments that demonstrated the high-fashion potential of specialized Australian wool fibers to be exhibited at national exhibition and fashion show to support the international sales of Australian specialist wool stocks (DAFWA, 2006a; Farren et al., 2006) (Figure 83).

Figure 83: Examples of garments created by five Western Australian designers. Source: (DAFWA, 2006)

The ‘Design for Comfort’ project was the first project undertaken as part of this PhD. At the start of the ‘Design for Comfort’ project, the researcher was in the first stages of learning to use the Shima Seki WholeGarment® computerized seamless V-bed knitting system. There were on-going struggles with the knitting on the machine and many accidentally ‘creative’ outcomes. The researcher would like to thank the ‘Design for Comfort’ team members and the Australian fashion designers for their support and understanding.

Undertaking this project and working on the WholeGarment® knitting system to produce unusual fabrics for the five professional fashion designers gave rise to several insights:

- It was possible for a knitwear designer with previous experience on a different type of computerized knitting system to create interesting fabric without formal training on the Shima Seiki WholeGarment® computerized seamless V-bed knitting machine.
- The built-in features of the Shima Seiki WholeGarment® computerized seamless V-bed knitting system made easy to interpret ideas for garments into simple fabrics and instant collaboration possible. The limitation is in moving away from the simple fabrics into using more of the creative potential of the technology.
- It is possible to do some experimental fabric design and prototyping on the Shima Seiki WholeGarment® computerized seamless V-bed knitting system using relatively ad-hoc, informal and trial and error approaches – providing that one is prepared to replace many broken needles.

- A possible new model of knitwear development process began to emerge that did not fully depend on knitting machine technicians and operators.

Garments for the ‘Wagin Woolorama Ambassador 2007’

This project involved designing, programming, and knitting outfits for the Woolorama Ambassador of year 2007 using 2/60 count four-end 100% Australian wool yarn on the Shima Seiki WholeGarment® knitting system. The garments were relatively conventional. An example is shown in Figure 84.

Figure 84: The ‘Wagin Woolorama Ambassador 2007’ in one of her computerized seamless V-bed knitted outfits. Source: Courtesy of Ms Crystal McIvor

This project was undertaken after the researcher had undertaken two short periods of training in Japan in using the Shima Seiki knitting technology. The following describes insights gained from undertaking this project:

- Garment making requires many detailed skills in using the computerized seamless V-bed knitting systems compared to making fabrics;
- A knitwear designer can create simple garments easily after two periods of training and some experience;
- Shima Seiki’s WholeGarment® design and production process for routine retail mass-market garments is simple and straightforward;

- It is possible for a knitwear designer to use the garment design system in to develop some slightly unusual garment shapes by combining and modifying the standard garment shapes; and
- It became more clearly apparent that garment design and production prototyping, fitting, sizing, and making garments to the point of and including the 1st sample can be undertaken by a suitably trained knitwear designer without the need for the knitting machine technician or the knitting machine operator.

In spite of the above insights, the researcher realized that to significantly extend the creative envelope of computerized seamless V-bed knitwear technology required a more detailed understanding of the system and, therefore, she decided to attend a third training program at Shima Seiki in Japan.

Knitwear design using ‘Merino Soul’ yarn with Bianca Gervasio

This project involved developing fabrics and WholeGarment® using ‘Merino Soul’. The Merino Soul’ yarn is a specially blended new type of 100% Western Australian Merino wool yarn. Garments were created using the Shima Seiki WholeGarment® knitting machine at DAFWA in collaboration with an Italian designer, Bianca Gervasio. The garments that were developed were exhibited at AltaRomAltaModa and can be viewed at its website (AltaRoma, 2008)(see, for example, Figure 85).

Figure 85: Garment created in collaboration with international fashion designer Bianca Gervasio for the AltaRomAltaModa fashion show in Milan 2008. Source: (AltaRoma, 2008)

Working on this project reminded the researcher of her earlier experience in the fashion industry. There were time constraints (though not as severe as typical of the fashion industry). There were gaps between the Italian designer's expectation and the possibilities provided by the computerized seamless V-bed knitwear design and manufacturing technology. These 'gaps' reduced during the course of meetings and design discussions over the course of the project.

Insights for the research from undertaking this project included:

- Understanding of the limitations of computerized seamless V-bed knitting systems is not widespread among designers;

- It became obvious there were significant advantages for the design outcomes if the person (the researcher) creating the novel fabrics for the designer has fashion design expertise;
- Given the right skills and processes, computerized seamless V-bed knitwear systems are effective for rapid prototype development of high-fashion garments for shows and collections. These skills and processes are very different however from those prescribed by the computerized seamless V-bed knitwear system manufacturers for use of their machines; and
- In using computerized seamless V-bed knitting systems for design and rapid prototyping of new high-fashion garments, language barriers are less problematic when the person directly creating designs on the knitting machine computer systems is trained in fashion design.

‘Cone-shaped Art artifact’

This project involved programming and knitting a New Zealand artist’s design of an unusual 9 meter long cone-shaped knitted art artifact for display at the Burswood Casino in Western Australia. The design used fluorescent yarn and although relatively simple in design, it pushed the boundaries of what could be knitted.

Designing and programming the artifact proved easy and the Shima Seiki WholeGarment® knitting machine can knit continuous fabric without problem (Miyake, Fujiwara, Kries, & Vitra Design, 2001). This meant that, in theory the 9 meter length of this artifact would not be a problem. The design used extreme modification of the skirt pre-registered garment shape. The researcher trialed several different mathematical series as the basis for the tapering and eventually settled on using a Fibonacci series to create the artist’s intended shape. This was the first time that the researcher had made a knitted art artifact rather than a fabric panel or garment. Although the researcher had been successful at programming, it remained of concern whether this gigantic piece would be within the envelope of knit–ability on this computerized seamless V-bed knitting technology. The design was first created as a miniature prototype (see Figure 86) using embedded features of the Shima Seiki *KnitPaint* software and then scaled to full size. There were some problems in locating sufficient quantities of the intended specialist fluorescent yarns.

Figure 86: Prototype of miniature cone-shaped artifact

In fact, however, the 9 meter artifact proved impossible to knit. The knitting machine ran out of machine memory whilst transferring the knit data from the apparel design workstation into the knitting machine. The artifact was a cone, an inverted tubular triangle shape. This resulted in the knit data being different on every knitted row, rather than the economy of memory available when rows are repeated. This appeared to be the cause of the memory overflow that blocked, and this be due to changing the knit data on each row to create the. Fortunately, perhaps, the problems with knitting a tapered artifact at such a large scale emerged before the problem of sourcing the specialist (and expensive) yarns was resolved.

Research insights gained from this project were as follows:

- Successfully designing and knitting a small copy of an artifact does not necessarily guarantee the design can produced at a large scale.
- For simple garment shapes, using simple mathematical approaches such as the ‘Fibonacci numbers’ can result in easier programming and knitting.

- Design processes involving specialist yarns require the yarn issues to be considered at the outset.
- There are limits to the size of artifacts that can be produced using the Shima Seiki WholeGarment® knitting system. The maximum size is limited by machine memory and the use of machine memory is dependent on the balance of repeating and unique knit elements in the knit data.

Reflections on design sources for computerized high-fashion knitwear development

Use of slits in the design of glamorous outfits

From 1988 to 1999, as a designer in a high-fashion knitwear company, the researcher created garments for middle-aged, wealthy customers who wanted to look fashionable and sophisticated. Most of the customers were full-figured women. The researcher developed a slit-based approach to design their glamorous garments. One example was a torso-length pullover with side slits, which also used the slit as a neckline.

Using slits was not a popular technique in knitwear industry at that time because it needed extra steps to complete the garment and a highly-skilled linking machine specialist for finishing. All of these added cost. These techniques were, however, acceptable in the context of a high-fashion house. For this fashion company, the researcher's slit style of designs worked out well, created many derivatives, and became one of the company's long-run bestsellers.

Up to that moment, the researcher had thought that mature women wished to cover up their aging bodies. It was interesting to have feedback from the sales staff that the customers liked the idea of revealing their bodies through the thin front slit because it did not fully conflict with their idea of modesty. Also, wearing a garment with a long front slit made them feel attractive.

Based on this experience, the realized using slit and slash-based high-fashion design via the computerized seamless V-bed knitting system provided an effective high-fashion knitwear design approach. Slit-based fashion design techniques are easily possible using the built-in features of computerized seamless V-bed knitting at relatively low cost, for example, in inserting side slits and front openings.

The fashion design potential extends further because slit and slash-based designs for garments offer opportunities for developing geometries for garments that can be worn in different ways.

Slash methods in high-fashion knitwear

Slashed knitwear can create sensuous garments when combined with tubes. More than 10 six different garment styles can be created out of a panel of fabric with six slashes. The beauty of using slash lies in transformation of their shapes once worn. Each slash becomes a visually attractive hole. The size and shape of these holes may vary, and also the length of the tube gets shortened when the slash is combined in a tube, according to the wearer's body fullness.

In computerized seamless V-bed knitting, slashes and slits are developed by engaging extra yarn carriers. This is unlike other knitted structures, which are usually created by alternating the number of needles in action at different positions of the needle bed – that is through the processes of knit, tuck, float, and transfer. From experience, it is unusual for a knitwear designer to be able to correctly visualize the final shape of the tube combined with slash, when being worn. The knitwear development process of the tube garment with the slash is a journey of uncertainty for the knitwear designer and dependent on the vagaries of the knit design software and the knitting machine. In other words, the knitwear designer explores using the CAD/CAM system how design sources – the tube and slash – undergo morphological changes. In the Shima Seiki SDS-ONE® CAD system, the tubular shape gets transformed into a group of dots that represent the number of stitches, texture (stitch pattern), and its shape. The area where the slash is intended is defined differently to inform the knitting machine CAM system where it needs to utilize additional yarn carrier/s. After this stage, the knitwear designer must follow the conventional programming path of the CAD design system to ensure the design knit data will work on the knitting machine.

Knitted panels

From the researcher's experience, the computerized seamless V-bed package software in SDS-ONE® *KnitPaint* is conceptually impregnable to a fashion designer. This is unusual because Japanese products are known for their easy-to-follow instructions. As a fashion designer with extensive experience in other forms of computerized knitting machinery, the researcher tried to teach herself how to operate the Shima Seiki garment template package making software with the assistance of its help file. She discovered that it was unusually complicated and technically required engineering rather than fashion design education, a fashion designer to learn directly from the help file.

Whilst on the training program at Shima Seiki, the researcher memorized the necessary technical information, a strategy that she had used for 12 years using Italian computerized knitting systems and realized that. The head tutor at Shima Seiki pointed out that it was necessary to try to understand the functioning of the system rather than memorizing the processes. The researcher reflected that it is a habit for many fashion designers to use rote memorization to cope with technical issues this way, rather than technical understanding.

Alongside the semi-commercial knitwear design projects undertaken in this PhD, the researcher explored the development of high-fashion bridal gowns in special fine wools. This aligned with her prior background in which designing wedding dresses was one of her specialties. It fitted well with the available yarns. In the DAFWA studio, most of the available years were in light creamy shades because they were undyed. The exploration was put aside because exploring the creation of wedding dress design details proved time consuming and that time was better spent on developing new fabric texture (surface) designs and garment shapes that demonstrated the novel wool fiber/yarn properties of the specialized wool yarns developed by DAFWA.

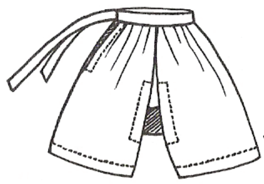
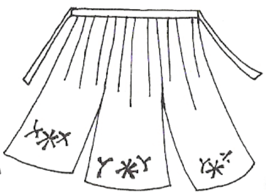
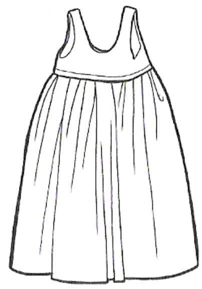
At a later stage in the research, the researcher was able to investigate the design of evening wear. The researcher’s knowledge in this area was limited to the technical side of garment construction. Addressing this insufficiency of knowledge resulted in her developing the 2D flat panel garment template as a contribution to evening wear. The researcher developed a range of evening wear tops that were based on the design features of scarves and aprons. The scarf is the simplest item to knit. Almost all new knitters start off knitting a scarf when learning how to knit. In creating woven wear, an apron functions the same as the scarf: the apron is the first item you work on when learning sewing.

The main design element of both scarf and apron is the flat 2D panel: the most basic and easiest thing to knit on the knitting system. Pockets, smaller version of panels, are the other main element of an apron, while straps are longer and narrower panels.

Frills and gathers, which are also panels, are optional, and give apparel a more feminine look. The researcher reasoned that if she could demonstrate a garment design based on the most simple and basic shapes using computerized seamless V-bed knitting technology, she could leverage these ideas into a garment development process for other knitwear designers to use the computerized seamless V-bed knitting to the point of *1st sample*.

The Dictionary of Korean Traditional Apparel and Costume Patterns and Designs provided inspiration. From experience, these kinds of book are useful design resources. Most traditional apparel is based on geometric shapes, especially on panels and tubes. The researcher's industrial experience was that knitted panels are more suitable for tops. Tops usually require more design details. Working on the panel designs gives more freedom to knitwear designers in garment construction and also to knitting machine technicians in programming. The tube is appropriate for both bottoms and simple tops. The shape retention properties of knitted fabrics mean that baggy and oversized dramatic design of trousers or wraps make knitted fabrics suitable for elegant evening wear. The fabric distortion can be hidden and other design elements can be added where more body freedom is required, such as bending arms, sitting down and kneeling.

Figure 87 shows Korean and other Asian traditional garments from two different design sources chosen for in terms of the feasibility of using these shapes with the machine. Images in Figure 88 were selected because they fit design parameters – panels, frills, gathers, and tubes and because they look simple and easy, and imminently flexible because of width and length variations, and can be worn over different parts of the body.

Panels	 너른바지  단속곳  수보로  너울
Frills	 무지기 7함 무지기
Gathers	 어깨허리

Tubes	

Figure 87: Inspirational traditional garments. Source: (Kim, 1998; Tilke, 1990)

During a trip round the Shima Seiki Total Design Center in Japan at the researcher's second training at Shima Seiki, she realized that a perfect example of a knitwear design primitive was a program for a simple 'unusual' flat panel top. One of the tutors provided her with a garment template which she, in the end, had no problem reproducing the garment and modifying it to produce many interesting knitted tops.

Figure 88 and 89 illustrate flats of the sample from two different angles using modified versions of the flat panel primitive of a garment. Figure 88 shows how it is developed on the knitting system while Figure 89 turned 90° clockwise displays how it is imposed on the body. Red crosses indicate possible modification areas.

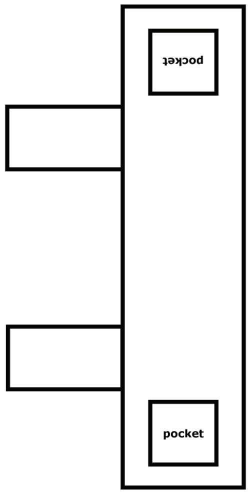


Figure 88: 2D flat panel garment template developed on the knitting system

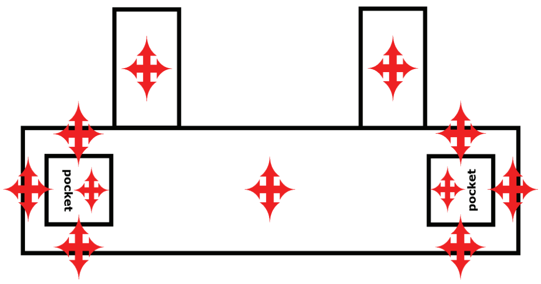


Figure 89: 2D flat panel garment template with possible modification areas

The program was created so that it could be used with various widths and lengths provided any change was a multiple of 4 stitches.

With some difficulty, the researcher adapted the above Shima Seiki program onto the knitting system at DAFWA. Theoretically, there should not have been any problems because it was created for the same system and the program ran well at Shima Seiki in Japan. In Australia, however, the automatic software settings of the DAFWA SDS-ONE® CAD system required modification. The situation was resolved only with the assistance of the Australian technical agent for Shima Seiki in Melbourne

It is unclear why Shima Seiki do not embed such interesting design possibilities in the knitting system. The researcher had seen some appealing styles at Shima Seiki which were attractive enough to appeal to designers. The possibility exists that those designs could have been reworked in various ways.

CHAPTER 11: Findings: Manufacturer's Training in Using Computerized Seamless V-bed Knitting Systems

This chapter describes the findings and insights about that the researcher derived from reflecting on her experiences of undertaking three periods of training in Japan provided by a computerized knitting system manufacturer. The reflections in this chapter cover the content and skills gained from each period of training; the role of note taking in improving training; and a review of the general factors that influenced the success or otherwise of the training from the researcher's perspective.

Findings: Personal experience of undertaking the first residential technician training at Shima Seiki in Japan

The researchers first residential training program at Shima Seiki's Total Design Center in Japan was different from expected and what had been agreed. This only became clear on the fourth day. The first second and third days of the training course followed the manufacturer's ordinary training schedule for a knitting machine technician at the beginner's level. These three days were different from the researcher's expectations because she had expected to be trained in specific programming areas that could be directly applied to her PhD and knitting projects. On the fourth day, after discussion with the instructor and the regional export manager, the researcher discovered that she was not on the training course that she had asked for. The tutor had prepared the regular training schedule based on a DAFWA staff member who had previously trained at Shima Seiki and who was less experienced. The researcher had asked for the majority of the training time to be allocated to training on knit programming using the *KnitPaint* and S•Paint software. Instead, the course was simpler and biased toward the easier *Design* apparel software for fashion design. This was a waste of time considering the researcher's five years' previous experience in commercial computerized knitwear design. It proved difficult for the Shima Seiki training establishment to modify their planned program. Instead, the tutor agreed to provide an additional intensive one-day lesson on programming the WholeGarment® computerized seamless V-bed knitwear system and recommended a future visit to Shima Seiki dedicated to programming the WholeGarment® computerized seamless V-bed knitwear system (see Appendix 2 for the timetable of the first training program).

AT the beginning of the course, there was some resistance to the researcher learning garment programming skills. During the program, the tutor became more accepting, understanding, and supportive. He provided three weeks of lessons on the background of WholeGarment® computerized seamless V-bed knitwear system knit programming. As a result, the researcher was able to program a raglan sweater full of missed stitch patterns (intentionally!) and knit it on the machine without the tutor's participation. This was seen as an unusual accomplishment. The tutor apologized for being so harsh, and the regional export manager congratulated the researcher on her achievement. The regional export manager commented not all trainees were successful using the WholeGarment® knitting technology in their first training, even some with technician backgrounds.

Focusing on WholeGarment® knitting technology meant bypassing the well structured lesson schedule for knitting machine technicians-to-be. Missing the technicians training, at the time, was less important in terms of the PhD research and obtaining practical outcomes for DAFWA. After three weeks of training on background of WholeGarment® knit programming, the researcher was transferred to another tutor to learn the apparel software for fashion design, 'SDS-ONE® *Design*' software (see Appendix 4 for details).

Findings: Second residential technician training at Shima Seiki in Japan

The second formal training at Shima Seiki's Total Design Center in Japan was undertaken by the researcher six months later. Whilst involved in the PhD and undertaking knit projects in Australia, some technical problems had appeared whilst operating the knitting machine. The level of these technical problems was clearly related to how advanced/difficult/complex the garments were. This seemed like an obvious time for the researcher to gain some additional expertise in using the WholeGarment® computerized seamless V-bed knitting technology, especially in more advanced knit programming and machine set up skills.

At Shima Seiki, the researcher requested to be taught by the tutor from their first training. Instead, however, she was assigned to the youngest tutor in the training Center. This offered an opportunity to be more assertive with training schedule. The researcher told the tutor what she wanted and asked if it was possible to also train an additional 3~5 hours after the normal day had finished. The young tutor was supportive. He was under time-pressure that he might not be able to cover everything the researcher had asked for.

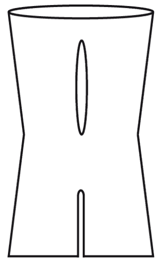
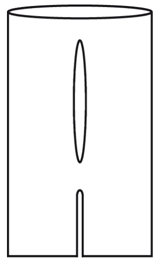
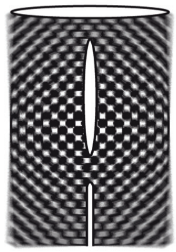
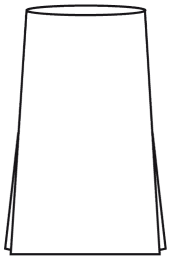
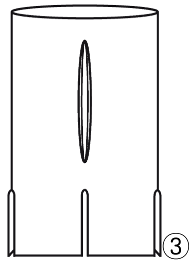
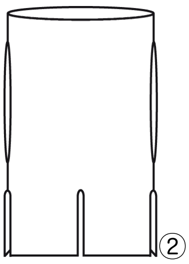
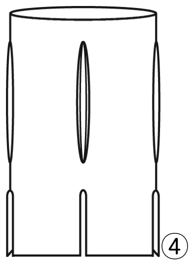
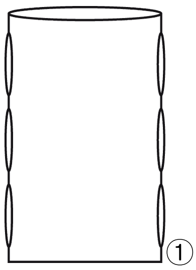
He tended to over-assist and, later, it became obvious that this level of enthusiastic support turned out to be disadvantageous. With hindsight, the researcher reflected that it would have been more helpful to let her do more of the tasks herself.

Unlike the first training, there was no specific schedule in this second training. Instead, the tutor worked on the basis of the researcher's 'wish list'. The primary process in this second Shima Seiki training course was by questions and answers between the researcher and the tutor. This was apparently reasonably normal and it appeared that almost all trainees preferred this form of customized training (see Appendix 4 for the timetable of this second period of training).

On Day 1, the tutor and researcher reviewed the researcher's wish list about what she hoped to learn and topics were ranked by mutual agreement. The tutor decided the order of lessons, and they undertook some basic training.

Knitting practice started from Day 3. From Day 5, programming and knitting practice were carried out simultaneously. The tutor and researcher spent a considerable amount of time on the knitting machines and this on-site practice greatly contributed to the researcher's building up confidence in operating the new WholeGarment® computerized seamless V-bed knitting technology.

On Day 5, the researcher presented the tutor with a revised 'wish list' composed of thirteen tube/panel drawings (with an associated new wish list of technical knitting problems to solve) (Figure 90).

		
C·Knitting-Vertical Center Slash-Shaped	C·Knitting-Vertical Center Slash	C·Knitting-Vertical Center Slash-Structured
		
KintPaint-Transform-Ex (delete top)	Both Side slits-Shaped	C·Knitting-Front & Back Slashes-Both Side Slits
		
C·Knitting-Vertical Both Side Slashes-Both Side Slits	C·Knitting- Front & Back Slashes-Vertical Both Side Slashes-Both Side Slits	Six-Side Slashes

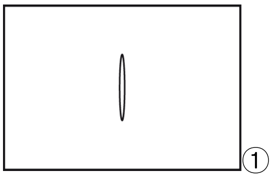
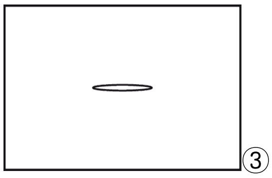
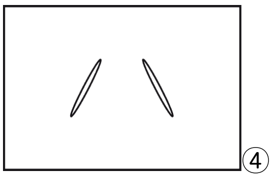
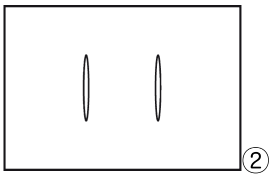
	
One-Vertical Slash	One-Horizontal Slash
	
Two-Flecharge Slashes	Two-Vertical Slashes

Figure 90: Thirteen preliminary drawings

On Day 7, the researcher reviewed and further amended her 'wish list' and went over the technical details with the tutor. This time, the research found it much easier to understand the tutor's technical explanations, in comparison with the first training. Frequent knitting practice under guidance of the tutor contributed strongly to acquiring this technical understanding and these skills (see Appendix 4 for details).

Throughout this second training course, there was a communication barrier that the researcher had not experienced with the first tutor. Communication was in English which was a second language for both the researcher and tutor. Korean was the researcher's mother tongue while Japanese was the tutor's mother tongue. The researcher found this upsetting because both the researcher and the tutor had to explain the same thing over and over again and the researcher was concerned things might not get covered in time. To help the communication, the researcher wrote or drew images to inform the tutor exactly what she meant. This communication problem lasted until the end of training course. Later, after the training program had finished, the tutor emailed the researcher some programmed files that had not been completed in time during the training.

Many of technical problems that had been identified during the PhD were addressed and resolved during this second period of training and the sketches and notes the researcher had made during the training proved useful later in the research.

Findings: Third residential technician training at Shima Seiki in Japan

After returning from the second formal training, the researcher received an email from one of the members of the 'Design for Comfort' team to ask if she would design WholeGarment® outfits for the Woolorama Ambassador of the year 2007 (see description earlier in this chapter).

During preparation of the garments for the Woolorama Ambassador, technical problems in the operation of the knitting machine emerged in relation to fabric take-down, loop length, and loop routines. These problems had not occurred previously while creating knitted fabrics. The designers in the 'Design for Comfort' project had appreciated the researcher's 'mistakes' and commented that they felt the mistakes made machine-produced fabric look more natural. This time, the need was to create something a WholeGarment® and it would be at a standard that was commercially viable and conventional, rather than experimental. In resolving these problems, the researcher realized the technical aspect of the knitting technology was more extensive than she had previously conceived it, and this led to her undertaking a third formal training at Shima Seiki, organized to start six months after the previous training.

In this third training program at the Shima Seiki total Design Center, both previous tutors were assigned to teach the researcher. The first half of this third training was with the first tutor. The second half was with the second tutor (see Appendix 2 for the training schedule).

There were significant differences in approach between the two tutors. The first tutor believed in building up strong technical grounding no matter what circumstances. The researcher hoped the second tutor would provide the help with the 'wish list' and left those assignments to the second tutor hoping for his support. Although this was not the researcher's opinion at the time, after long reflection, the approach of the first tutor seems to be the best solution where time allows. The first tutor focused on the researcher's 'understanding' or 'lack of understanding' of technicalities. He pointed out her tendency when encountering difficulties to try to memorize solutions in preference to gaining understanding. The first tutor explained each technical matter until the researcher understood it. The tutor's obstinacy upset the researcher several times but later she realized his approach enabled her to be more resourceful when she encountered technical problems back in Australia.

In this third training, knitting practice was undertaken from Day 1. The first part of the third training program focused on operating the knitting machine following a standard work flow for the machine setup. This requires a comprehensive set of checks before any knitting. This approach is time-consuming and tedious. It minimizes, however, the appearance of many of the most significant technical knitting problems. This first part of the training program consisted of going back and forth to the knitting machine alternating programming and knitting practice.

The researcher took notes alternatively with programming and knitting. During this third training program she observed that the pressure on time required her note-taking style to become simpler, more casual, and used more sketches and fewer words than her normal practice. At the time, the researcher felt insecure about this because she is a compulsive note taker and was concerned about whether or not she would be able to fully recreate the memories of all the practices and reflect on them for her research when she returned to Australia. In fact, this proved not to be a problem and the memories were clear from the sketches.

In the first part of the third training, the tutor and the researcher were both aware that the allocated time was so short there would be insufficient time to go over knit programming package development in detail. They agreed to focus on the extreme manipulation of existing ‘preregistered garment shapes’ in *KnitPaint* software.

On Day 4, the researcher showed a revised wish list to the tutor. Time was running out. Most of the training time in this first period was used to learn technical aspects of programming and understand the causes of technical problems. It became clear what the tutor was trying to achieve: covering any technical issues the researcher had missed out on her first training.

After studying with the first tutor, the researcher was concerned this would be her last chance to organize technical skills needed for her research. At ‘Nanpuso’, where she was staying for the training, the researcher undertook a two-day review and revision of the material and training by herself over a weekend to make sure all aspects of the training were fully absorbed and that she was ready for training with the second tutor in the second part of this third training program. Her review focused on a tube that was a combination of all the technical problems that she had dealt with for a week of training course (Figure 91).

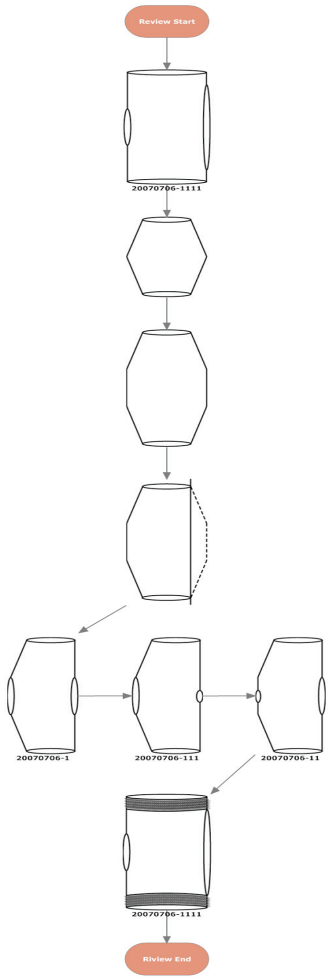


Figure 91: The review process of programming

The researcher recalled that the first tutor had praised her for the above problematic tube as a training issue and advised that the tube would be a good teaching material for students. Initially shapes were created in plain stitch pattern and then once successful at programming the shapes, the researcher imposed different stitch patterns on the shape. Cable patterns turned out to be hardest for programming and knitting and least attractive.

The young tutor from the second training program behaved in much the same way and stayed watching what the researcher was doing; whether she was working on programming or knitting practice. The researcher appreciated this close attention and support. It contrasted with the education from the first tutor, who was the head tutor of the program and often had to leave to take care of other business.

In the period since the second training, the young tutor's communication skill in English had improved and this time the researcher did not have any trouble understanding him. Again, he agreed to work additional hours over and beyond the conventional training program time. Other trainees thought the researcher must have been a Shima Seiki agent from overseas because she worked after hours with him for four days, starting from 8:30AM to late at night.

After the first day with the second tutor, the researcher asked him not to alternate programming and knitting practice simultaneously. The first tutor alternated programming and knitting practice as the best way to learn the depth of technical issues. This approach was, however, time-consuming. In the second part of this third training program the researcher had already become more competent in using the knitting technology. With time being short, it required a different approach to cover all the priority topics for the research projects. These were all covered within the training program, although not as deeply as had been envisaged.

At the end of this third training period, the researcher was advised to leave some time before any returning for any further training. Apparently, no trainee returned at six month intervals as she had. This had been unusual and was puzzling for the trainers, although they understood it was an effective way to reach the level of competence needed for the research (see Appendix 4 for details).

Findings: Using different forms of recordings to maximize training effectiveness on computerized seamless V-bed knitting systems

The researcher used several approaches to record her experience and learning at the Shima Seiki Total Design Center in Japan to make the most out of each residential training.

Through the five weeks of the first training, she used a tape recorder. This proved to be less useful than expected because she found she relied on it too much, and ignored reinforcing what she had learned by revisions of the material on site.

In addition, the researcher used a notebook to record keywords and phrases for basic issues with more detailed notes taken for complicated issues. From her prior experience, detailed sequential note taking was the best for certain functions or workflow of specific software processing. There was opportunity for more detailed and sequential note making when revising after each days training class by referring to the keywords and phrases recorded in class. The researcher found it was useful while revising in break time or after class to flag specific information that she did not understand by leaving an empty space marked with a question mark in the notes. This prompted her to ask questions of the tutor after that break. This appeared to also have the effect of giving the message that the researcher was taking the training seriously. The tutors believed many trainees viewed having training opportunities in Japan as being on holiday. Using these 'markers' was also helpful for the researcher for a final review and revision of her learning on the last day of each training program to check if anything had been missed or if something needed to be reinforced by the tutor.

Personal reflective evaluation of the training processes and knowledge acquisition provided by the Shima Seiki training programs

Throughout the three residential training programs, the researcher observed many examples of 'one-to-many' training sessions in which a group of trainees gathered around one tutor to be taught (Figure 92). This appeared to be the standard training mode at Shima Seiki.

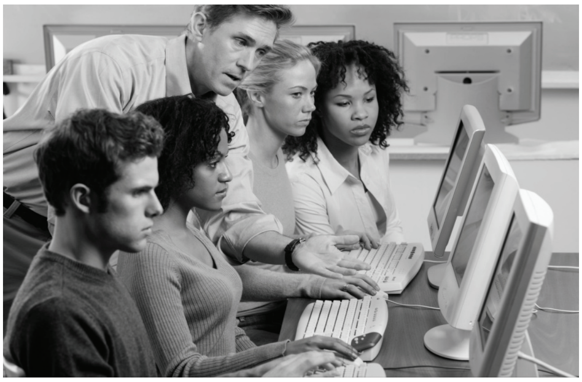


Figure 92: Example of 'one-to-many' training mode. Sources: (Microsoft Corporation, 2010)

Prior to undertaking the three training programs at Shima Seiki, the researcher was concerned about working with trainees on different level of technicalities in the same group. She was concerned on the basis of discussions with others that the combination of different levels of technical knowledge and different levels of command of English (and Japanese) by different members of a group would make the training inefficient and ineffective. Shima Seiki prioritizes matching the overseas trainees' level of technical skills rather than their level of English. In this context, it was helpful that DAFWA and Shima Seiki agreed to the researcher having one-to-one training.

There were differences even in the same one-to-one training modes. The first tutor progressed the training rather remotely and remained well out of personal space, sitting next to the researcher only when demonstrating the CAD system and at lunch sitting with the other tutors rather than the trainees. In contrast, the second tutor sat alongside her all the time, even through lunch.

The different attitudes of the two tutors extended to other aspects of the training. The first tutor hardly initiated conversation and talked only about training-related matters. The researcher at times thought the first tutor did not like to work with a woman and this thought made it difficult to ask him questions which slowed progress – especially on the first training program. The young tutor of the second training program was friendly and talked openly about a wide variety of issues. This friendly attitude made it easier to feel comfortable training with him and easier to ask him questions including those that were unasked in the first training.

At the concluding of the third, final training program, the researcher could see that her next need for training was some distance into the future. The development in the research of the new integrated knitwear design and manufacturing process to the point of *1st sample* seemed on track, and the researcher had additional training materials to explore that were uncompleted outcomes of collaborations between herself and the tutors. Both tutors had been compassionate about the researcher's remote research environment and suggested a method of simulation of on-the-job training, i.e. - alternating programming and knitting practices whenever necessary (see <u>The Third Training</u> in Appendix 4). This approach was time-consuming, tedious, and more work for tutors as well as for the researcher, but was beneficial in the longer term of the research. The simulation of on-the-job training was the most effective because it demands more mental and physical energy both from tutors and trainees and the learning is tightly linked to practical work situations.

In regard to knowledge transformation: the first training gave the fundamentals; the second gave the researcher a better theoretical understanding of the computerized seamless V-bed WholeGarment® knitting system; and the third training helped the researcher with learning many of the details that gave practical expertise in using the knitting technology.

Unexpectedly, learning and troubleshooting using the manuals turned out to be more of a problem than expected. Japanese are acknowledged as being expert in transforming tacit knowledge into explicit knowledge via codification and articulation (Nonaka & Takeuchi, 1995). Tacit knowledge is usually transmitted via training and personal experience and cannot be directly codified. Whereas explicit knowledge can be transferred and learned by language by using technology (documents, videos, audio, images etc) in which knowledge can be stored, transferred and communicated (Toolbox for IT, 2010)

From experience, Japanese manuals for hand knitting, crocheting, and hand-framed knitting are typically excellent. Although, the researcher is unable to read Japanese, the visual expressions on these knitting manuals are typically so clear that they are easy to understand. The researcher had often been amazed by how Japanese manuals captured the right steps and articulated the whole process wordlessly. In contrast, the researcher found that Shima Seiki's WholeGarment® knitting manuals are some way from that standard of usability.

CHAPTER 12: Findings: Education and New Integrated Computerized Seamless V-bed Knitwear Design Process

A crucial question for the development of the new integrated high-fashion knitwear design and manufacturing workflow described in earlier chapters is whether it can be taught and learned by fashion design professionals and fashion design students.

An aim of the development of this new integrated high-fashion knitwear design and manufacturing process was to resolve the problems of the current approach to computerized knitwear design, which focuses on removing the role of the knitwear designers and reducing design to choice from a selection of standard general-purpose garments.

Obviously, the new workflow and associated skills can be learned because the researcher has herself learned sufficiently to produce high-fashion designs to the point of *1st sample* using this technology without recourse to technicians. This was done, however, after learning a substantial part of the technician and knitting machine operator's knowledge via training in courses at Shima Seiki in Japan. In addition, the researcher is highly experienced in fashion design and highly motivated to learn. The real question is whether conventional fashion design students or contemporary high-fashion designers can learn to use the computerized seamless V-bed knitting technology as part of their design development.

Whether it is possible to teach the new design processes, methods and workflows developed in this research was tested via five teaching and learning projects. These consisted of:

- Short high-fashion knitwear garment design course delivered in 2007 at Curtin University focusing on the development of designs using the researcher's new high-fashion knitwear design approaches and her computerized templates for garments with slashes and slits base on simple geometric tube shapes. This course involved thirty students;
- A modified repeated version of the above course delivered in 2008 at Curtin University to a different tranche of students;
- Two half-day seminars for TAFE fashion students and academic staff in 2006 and then in 2007 (approximately ten persons in each seminar);
- A profession practicum 'internship' in 2008 for three selected Curtin students to produce miniature garments; and

- Tutoring based on previous production of garments for a public dance performance.

High-fashion knitwear garment design course using researcher's new knitwear design approach (2007)

In 2007, the researcher in collaboration with Ms Anne Farren, Head of Fashion Design at Curtin University, and Mrs. Emma Basden, a wool specialist and project manager at DAFWA developed a new fashion design course for second year Fashion & Textile Design students to learn knitted garment design and manufacture practices using computerized seamless V-bed knitwear systems. This course, which used the DAFWA Shima Seiki SDS-ONE® knitting system and DAFWA Fashion Knitwear Design Research Studio was a pilot exploratory education project that utilized a specially customized version of the researcher's new integrated high-fashion computerized knitwear design and manufacturing process.

This course occurred after the researcher completed the third formal training at Shima Seiki in Japan in which she devised a way of creating high-fashion knitwear based on using multiple slashes and slits in geometric tube-derived garments. The course used the researcher's computerized seamless V-bed knitwear garment templates that the technical staff at Shima Seiki in Japan had developed for the researcher as custom pre-registered garment shapes.

Students were allocated between them twelve (12) tubular geometric shapes 'garment primitives' as a starting point for them to design and create garments using the Shima Seiki WholeGarment® knitting system. Their task, working in pairs, was to combine two tubes, one tube from each student, or manipulate one tube as a pair to create a garment design. Each garment must be designable, programmable, and knittable on the Shima Seiki WholeGarment® knitting system. The pre-knitted tubular shapes are shown below in Figure 93.

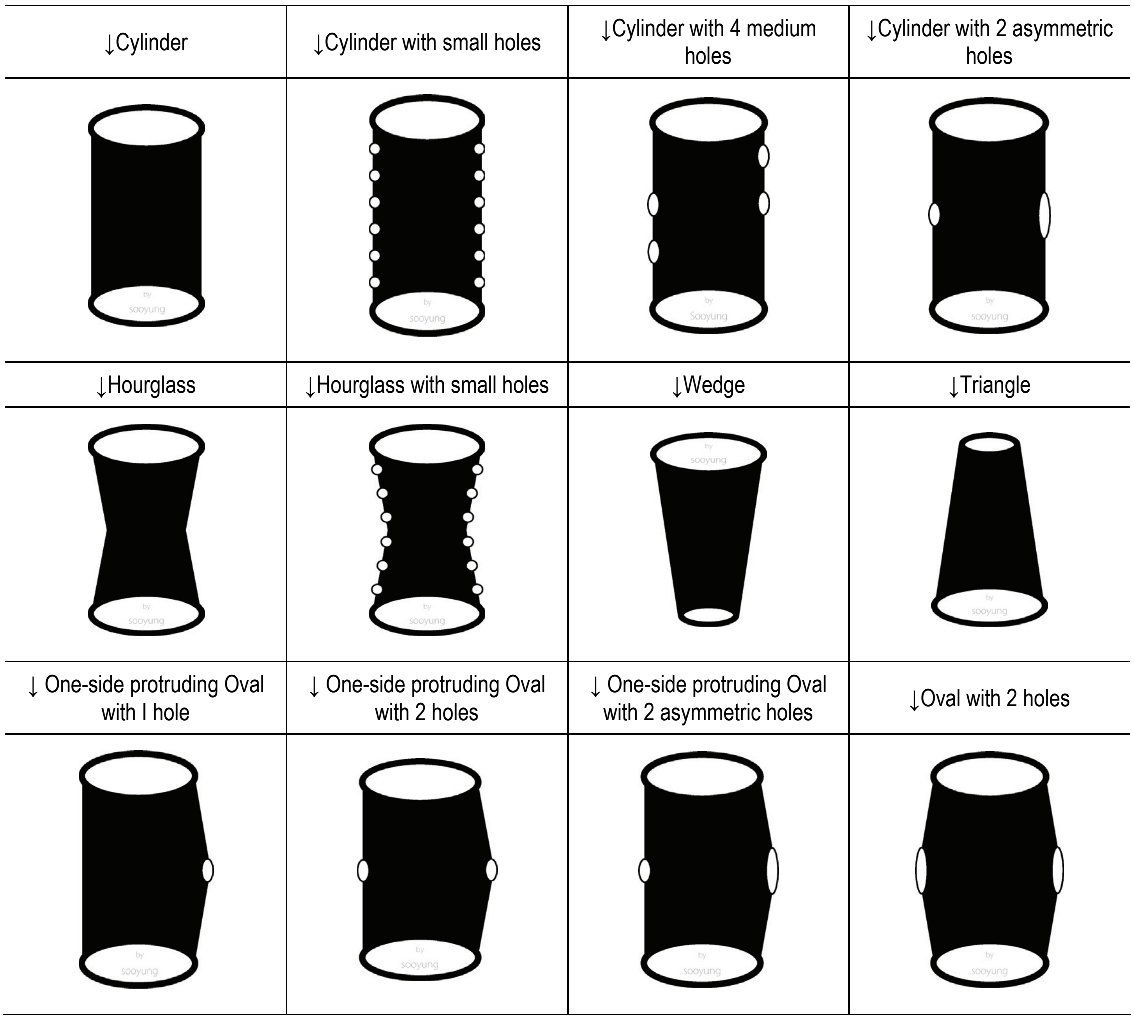


Figure 93: Twelve (12) tubular knitted shapes

The timetable for the course was very tight because access to the knitting studio was limited to only six students at a time, which meant each session of the course was repeated five times. With this highly condensed schedule, staff support for individual students' design work was very limited. The details of the course are listed in Table 16 in Appendix 1.

During the course, it became clear students needed additional prior knowledge and real time design guidance to enable their designs to be more easily programmable and knit-able. To address the issue, the researcher provided a supplementary class to provide students with a broader and more in depth introduction to computerized seamless V-bed high technology knitting systems provide more contextual industrial information that helped them better locate the knowledge and experiences during the course. After six lessons including the introductory class (6 hours in total for each pair of students), most students were able to create high-fashion knitwear designs that were programmable and knittable using the WholeGarment® computerized seamless V-bed knitting system to a standard and quality that were suitable for public display. Examples of garments developed in this 2007 course are shown in Figure 94.

Figure 94: Examples of knitted garments developed by students in 2007 using slashes and slits in tube-derived garment shapes designed and knitted using the researchers new knitwear design approach. Source: (DAFWA, 2007)

The outcomes of this course confirmed the researcher's judgment from her earlier experience in Korea as an adjunct Professor in Fashion and Textile CAD systems that a five session course with supplementary class is sufficient to introduce her new design approaches for computerized seamless V-bed knitting technology to fashion design students.

Reflecting on the course after it was completed pointed to two additional teaching and learning issues to address: yarns and student confidence and engagement. Yarn issues proved to be more significant than expected. Some knitting yarns, especially acrylic yarns are more tolerant of less than perfect knit programming and set up codes. Obtaining suitable easy to knit yarn for the students to knit prototypes proved to be more significant than technical knitting issues. Students' progress was slowed due to yarn issues and their learning progressed more quickly once suitable easy to knit yarn was acquired.

There were differences between students in terms of their engagement and confidence. Some students seemed overwhelmed by the high technology knitting system. In an assessment and review two weeks after the final session of the course, it became clear that students were significantly concerned they might ruin their knitted garments. This worry had the effect of restricting their creative work. The researcher decided to explore how best to address this issue at a later time.

In conclusion, this pilot version of a new short fashion knitwear design course for computerized seamless V-bed knitting systems was successful enough for the course to be included as a core unit of the Curtin Fashion Design program for the following year, 2008. The success of this course, built on the outcomes of the PhD research, strongly indicated students could easily learn to use the researcher's new integrated high-fashion computerized knitwear design and manufacturing process and design methods to produce high-fashion garments.

Modified high-fashion knitwear garment design course using researchers new knitwear design approach (2008)

The 2007 knitwear design course described above was repeated in a modified form in 2008. The modifications to the course were intended to give students increased opportunity and encouragement to engage with the technology and experiment more creatively with their garment designs and the computerized seamless V-bed knitting design and manufacturing technology. In this course, students were required to include an additional garment review at an intermediate stage. This gave them an opportunity to see other student's work and creatively revise their own designs and prototypes before final garment production. This seemed to provide improved outcomes and students seemed to appreciate the increased refinement of the design process.

The modified course in 2008 progressed smoothly in all aspects. Students appeared to be engaging more with the activity and producing more interesting designs. Technically, their use of the knitwear system began to extend. In 2007, students' garments were based wholly on the use of *KnitPaint* with the pre-registered 'tube' garment templates. In 2008, some students' work extended to basic use of S•Paint software which extended the potential creative envelope available to students. Over future years it would be expected that this trajectory of extending the technicality of student's use of the knitting system will continue.

The modifications made to the course on the basis of insights, lessons learned and reflections on the 2007 pilot course are detailed in Table 16 in Appendix 1. One significant change was in terms of a new process for exploring design opportunities given by stitch pattern choices. Each pair of students was asked to choose a knit stitch pattern preference before the start of the course by looking at the surface design library of the CAD system. They were allowed to exchange their stitch pattern with another pair and interestingly, most pairs of students discarded their initial selections and changed to a more 'popular' or conventional stitch pattern.

The yarn distribution to students was changed compared to 2007. More yarn was allocated and both acrylic yarn for the prototype and wool for the final garment were given to each pair of students. These extra resources enabled students to explore more and extend their design boundaries. The course timing was modified to allow extra time at strategic points. Beneficially, these changes also helped avoid a timetable clash between the final garment embellishment and other courses in their Fashion and Textile Design degree.

During this 2008 course, six changes were made to enhance the quality of the education process in learning the researcher's new integrated high-fashion computerized knitwear design and manufacturing approach. These were:

- Increased time to review the surface design library of the CAD system with access to an expert who knows both the knitting system and the available stitch patterns;
- Access to real knitted swatches of examples of patterns in the design software library for students to see and feel. It can be hard to imagine what a CAD generated image of a stitch pattern (virtually knitted) looks and feels like in reality;
- The number of visual design choices for the students were reduced to subset that work well together. The high number of potential detail design choices (more than 800 stitch pattern variations and 66 garment shapes) unnecessarily takes up too much of students' time and energy in reviewing them and choosing between them. Professional fashion designers have strategies for managing high numbers of choices that cannot be expected of novice fashion design students (see, for example, Langrish & Abu-Risha (2008));
- Prior to the course, students were encouraged to gain hands-on experience and skills in hand/machine sewing, hand-framed machine knitting, hand knitting and

crocheting. These provide basic knowledge to help students understand the basics of high technology knitting system;

- Improved student course information emphasized the workload intensity of this course due to the limited access to the system and the need for thorough pre-class preparation to get the most from each session; and
- Time was allocated for students to create a second set of knit data to correct their designs for differences between their garments when knitted with acrylic yarn and the final wool yarn. Garments knitted in acrylic yarn are bigger and flatter than those made in wool using the same knit data. In the 2007 course, students used a single knit data file and the size and shape of acrylic prototypes were often very different from the final garments.

Improved student learning and design outcomes were observed in this second course. The course ran more smoothly and appeared to engage students more deeply in their creative design activities than the 2007 course. Unexpected outcomes that were observed included a pair of students being particularly inventive in how they documented *design specifications sheet*s for production; another pair spent time deeply exploring the use of S•Paint images within SDS-ONE® *KnitPaint* to created WholeGarment® patterns. Broadly, this second course provided additional confirmation that the researcher's new integrated knitwear design and manufacturing process is straightforward for fashion students to learn. Significantly, it also indicated that there are opportunities for further development of the education process.

TAFE seminars

During the same period of 2007 to 2008, the researcher conducted two half-day seminars for TAFE fashion students and academic staff. Conceptually, the seminars covered similar territory to the Curtin University fashion design courses described above but in one-day form.

The seminars comprised field trips to the DAFWA Fashion Knitwear Design Research Studio for the students to view the Shima Seiki knitting technology in operation. Their hands-on experience in hand-framed knitting machines meant TAFE students' had a different and more practical understanding of computerized seamless V-bed knitting technology compared to university fashion students. This additional practical understanding seemed to improve their speed of learning about the new integrated high-fashion computerized knitwear design and manufacturing process.

Besides the demonstration of the technology, the program primarily comprised extended question and answer sessions and demonstrations. There were many questions from accompanying tutors as well as from the students. All of them were also busy taking photos and going through samples and seemed amazed at the potential of this technology for high-fashion design and knitwear production.

It was at the first TAFE seminar, that an academic who had machine knitting experience and had taught the subject for many years at a TAFE drew attention to the need for students to be able physically to feel the tactile qualities of knitted surfaces and fabrics as compared with the 'visual' representations in the design software. This issue of 'virtual' versus 'actual' aspect of knitwear design has deeper implications and has been identified later as a potential topic for future research.

The second TAFE seminar focused more on business issues in the knitwear industry. This direction was driven by one TAFE tutor who was particularly business-minded. The students attending the seminar also proved to be very interested in the business aspect of using computerized seamless V-bed knitwear design and manufacture. In other respects, the second TAFE seminar was similar to the first.

Both seminars provided additional support for the ideas that students and experienced designers could relatively easily learn the skills necessary for the new integrated high-fashion computerized knitwear design and manufacturing process.

During these TAFE seminars, it was possible to see slight differences between fashion design education at a university and technical institution. On reflection, the researcher found this echoed her earlier experience that suggested universities and technical institutions were different in their foci of emphasis in fashion education. She graduated from the Fashion Institute of Technology in New York with an Associated Applied Science (AAS) degree equivalent to the Advanced Diploma from an Australian technical institution. In industry she had attended the Institute Francais De La Mode, Paris in France three times (1991~1993) and taught at a computerized knitting school for two and half years in Korea. After twelve years of industry experiences, she completed a BA in Fashion and Textile Design at an Australian university. Her previous experiences indicated technical schools tend to push students to acquire useful industry skills. As a result, these students become more technically oriented and organized than university students who have increased emphasis on being 'creative'. It suggests teaching the new integrated knitwear design and manufacturing process in these two different educational contexts will need to take account of their differences.

Professional Practicum internship

In 2008, three Curtin second year students majoring in Fashion and Textile Design were offered a professional practicum 'internship' in industry practice on computerized seamless V-bed knitwear design and production. The researcher's role was to act as a 'commissioner' of garments to provide some of the feel of 'internship' in industry practice and also to provide some tutoring support for the students. The students were required to develop creative high-fashion garment samples designed and knitted at the miniature scale of ¼ of female size 8 (Figure 95).

Figure 95: Miniature WholeGarment® dresses. Source: (DAFWA, 2008)

During the practicum, the students learned about the computerized seamless V-bed knitting design and manufacturing process. Educationally, the practicum and internship concept offers many potential benefits. In this case, however, it seemed to fulfill less than its full potential. This appeared to be in part because students did not fully understand how best to take advantage of this learning format. These issues were echoed in the quality of design output. This practicum demonstrated that while students are able to learn many aspects of the knowledge and skills of the new integrated high-fashion computerized knitwear design and manufacturing process, the teaching and learning process matters for them to be able to gain the potential benefits for their own professional development.

Tutoring based on previous production of 'dance performance knitwear'

This education program involved tutoring students in the redevelopment and presentation of previously designed programmed and knitted tube garments. These garments were designed to be used in a dance performance at a local conference at The University Club of Western Australia in July 2008. The program involved close teamwork with a large number of participants. The researcher's experience of the process leading up to the dance performance itself was unusual as the project was non-hierarchical. Each of the team members had a portion of work to complete. The researcher's associate supervisor, Professor John Stanton led and managed the project overall, and regarded his role as not being to tell the team what to do, but rather to provide the team an opportunity to highlight their efforts.

This project demonstrated that the new integrated high-fashion computerized knitwear design and manufacturing process can be easily integrated into both hierarchical and non-hierarchic workflows and can work well in situations involving multiple stakeholders and participants.

Examples of the garments that were designed and produced are shown in Figure 96 below.

Figure 96: The dancers in their moves. Source: (DAFWA, 2008)

CHAPTER 13: Conclusions

This thesis has described the researcher's application of a participatory action research approach to improve knitwear design practices in the use of computerized seamless V-bed knitting systems in the international high-fashion apparel knitwear industry. The research addressed, along with other issues, the widely identified suite of problems associated with the introduction of computerized seamless V-bed knitting technology in high-fashion knitwear design. To maximize mass-market retail design efficiency and as a unique selling factor, manufacturers of seamless V-bed knitting systems have automated the more routine aspects of knitted garment design and this has minimized the possibility for involvement of high-fashion knitwear designers. From a high-fashion perspective, this is particularly unfortunate because computerized seamless V-bed knitting technology offers a unique benefit to high-fashion in its potential for designing and producing low runs of radically styled high-fashion garments.

This research has viewed computerized seamless V-bed high-fashion knitwear design and production as a socio-technical system (STS) containing a complex integration of human activities and technology factors. In line with this approach, the researcher has applied activity and workflow analysis and process mapping to identify the current blocks to participation of human high-fashion designers; to investigate empirically how these blocks can be removed; and practically to explore and extend the creative potential of the computerized seamless V-bed knitwear systems.

The research outcome can be seen in terms of the development of an improved model of the roles, tasks and work processes of high-fashion designers using computerized seamless V-bed knitwear design, such as the Shima Seiki WholeGarment® knitting system. The research identified generation of *1st sample* as being an important division between the 'design' and 'production' aspects of the STS and as such focused on improving the design and development processes prior to and including the creation for the *1st sample* knit code and actual knitted sample. In addition to the development of new workflow, process and role models, the research also resulted in the identification of new design methods and new approaches to fashion design education for high-fashion knitwear designers. These outcomes potentially offer significant benefits in knitwear design, reduction in time to market, reduction in design costs, and potential increase in the creative solution space for high-fashion knitwear design.

In line with the above, data collection and analyses in the research have focused on developing improved design processes and practices, redefining professional roles and tasks, and trialing education programs intended to bridge the gap, up to now, incommensurably different practices of knitwear designers, knitting machine technicians, and knitting machine operators in making garments to *1st sample* stage.

To summarize, this research resulted in a new workflow process that provide total control over the design of garments to fashion designers to and including the creation *1st sample* and have removed the need for machine technicians and knitting machine operators in the high-fashion knitwear design process.

Together, the data collection, analysis and practical activities undertaken have answered the research questions and provided a resolution of the major problem addressed by the research. The result is a new industry-wide approach for high-fashion use of computerized seamless V-bed high-fashion knitwear systems in international knitwear design and manufacturing industries. In addition, the research resulted in many practical insights for improving knitwear design practices and education using the new computerized seamless V-bed technologies, and identified several opportunities for future research that extend the benefits of the use of this technology in the international high-fashion and mass-market knitwear industries.

The research demonstrated it is possible for a professional knitwear designer to undertake all of the current three roles in the design and production of computerized seamless V-bed high-fashion knitwear to the point of *1st sample*: designer, machine technician and knitting machine operator. It requires, however, some additional training and practice experience over and above that which is currently taught to novice knitwear designers in fashion education. The researcher has named and envisaged this new profession which integrates all three roles into a high-fashion knitwear 'designer-interpreter'.

Answering the three research questions

In the opening chapter, three research questions were identified whose answers would contribute significantly to resolving the research problem described, in brief, is that 'computerized seamless V-bed systems fail to draw on the expertise of knitwear designers and have a range of problems due to conflicts between the different work roles.'

The three research questions were:

- How much of the roles of the knitting machine technician and knitting machine operator can be undertaken by the knitwear designer to the point of 1st sample garment?
- What would be a more efficacious high-fashion knitwear design development process to the point of 1st sample with the knitwear designer undertaking more of the roles of the knitting machine technician and knitting machine operator?
- Can this new approach be taught?

The *1st sample* is the crucial milestone in the design and production process for computerized seamless V-bed knitwear.

Significance of the *1st sample*

The '*1st sample*' is the first physically knitted sample of the fabric or garment knitted with the yarn intended to be used in production. The *1st sample* is an accurate and complete representative example of the intended designed outcome knitted directly from the knit code developed for the garment.

The 'completion of *1st sample*' is a significant milestone for both knitwear designer and knitting machine technician. At this point, the knitwear designer can verify that the proposed garment is knittable; can confirm that the knitting software produces the garment that was intended; and can check the yarn and fabric performance and garment shape. The *1st sample* is made in the yarns that the final garment will be produced in, as distinct from the earlier prototypes that are made in relatively cheap acrylic yarn during the stages where the software is being modified to enable knit-ability.

1st sample stage is also important in terms of the roles of the different participants in the computerized seamless V-bed knitwear design and production process because prior to this point the focus is on creative experimentation, design, and prototyping that is primarily in the realm of the knitwear designer. After *1st sample*, the work primarily involves the knitting machine technician and knitting machine operator to optimize the knit code for fast production and the actual production of fabrics or garments.

Research Question 1: How much of the roles of the knitting machine technician and knitting machine operator can be undertaken by the knitwear designer to the point of 1st sample garment?

The research identified, and empirically tested across 8 semi-commercial projects and 531 designed and knitted outcomes, that a high-fashion knitwear designer can manage and undertake the whole of the process up to and including the creation of *1st sample* including all of the roles of the knitting machine technician and machine operator.

In the new integrated design process developed in this research, the new knitwear designer role includes to managing and undertaking all aspects of the design and production process to the completion of *1st sample* of knitwear.

Besides providing direct fashion design input as the dominant factor in the creation of the garment design, the raft of problematic interactions between designer and machine technician are minimized. In addition, the transition procedure to the knitting machine technician following *1st sample* stage is more direct, smoother and more accurate because there is an actual sample for the knitting machine technician to examine alongside the knit code and *design specifications sheet*. From experience, the work of knitting machine technicians is more efficient and effective when they have actual samples in hand compared to when they are given only the *design specifications sheet*s as in the current process.

More importantly, from the high-fashion designers' point of view, the changes enable them to experiment directly with the computerized seamless V-bed knitwear design and production technology. This enables high-fashion designers to develop exactly the garment designs they have in mind; simultaneously to explore and investigate the unusual potential of this technology; and to expand the envelope of its artistic and creative potential beyond that of retail mass-market knitwear design as prioritized by the system designers.

This change in roles is a paradigm shift in computerized seamless V-bed knitwear design and production in which the knitwear designer is able to make (design, program, and knit) *1st sample* without input from the knitting machine technician and machine operator. This also eliminates a portion of the interactions between the knitting machine technician and knitting machine operator after the design specifications hand-over.

Compared to the conventional computerized seamless V-bed knitwear workflow process, the proposed changes in roles up to *1st sample* remove significant amounts of the machine technician's tasks as shown in Figure 97 below. This shortens the knitwear development process as a whole (see the one after the next, Figure 98).

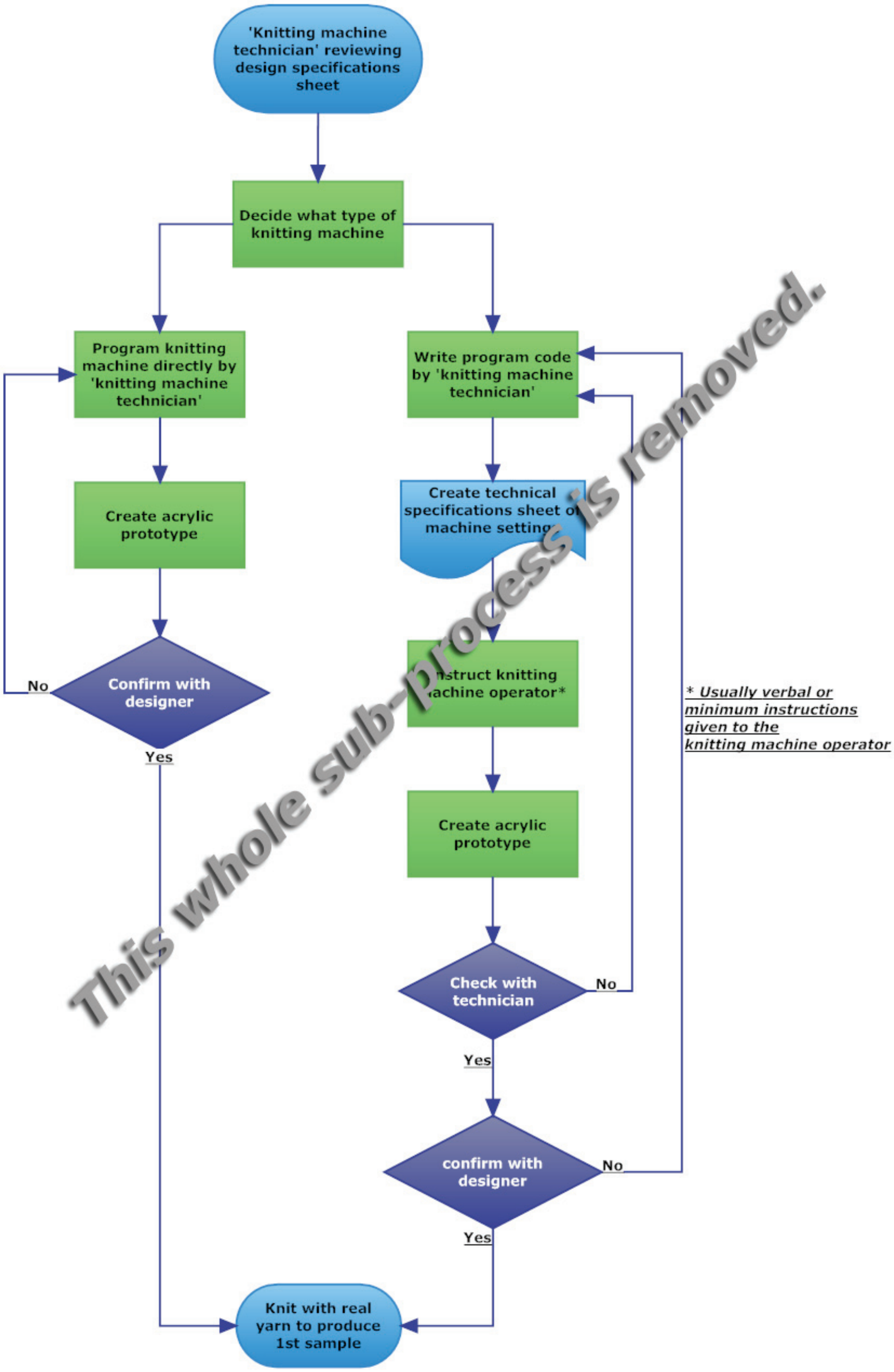


Figure 97: Knitting machine technician's activities after *design specifications sheets* hand-over

The analyses that underpinned these suggestions for changes to roles were devised for the use of the computerized seamless V-bed system at an industrial production scale for use in factories with many knitting machines. In addition, however, by enabling the high-fashion knitwear designer to undertake all the activities of the computerized seamless V-bed design and production to the point of *1st sample* also provides the basis for a new form of high-fashion craft (thanks are here due to the reviewers of this thesis for pointing to this potential of the change of roles). This outcome is described in more detail in the later section in this chapter on 'Future Research'.

The findings from answering this first research question open up the potential for different forms of workflow process of which the most obvious is described in the answer to the second research question below.

Research Question 2: What would be a more efficacious high-fashion knitwear design development process to the point of 1st sample with the knitwear designer undertaking more of the roles of the knitting machine technician and knitting machine operator?

Identifying an improved knitwear design development process was undertaken empirically through the researcher undertaking multiple real knitwear design and production projects and special training at Shima Seiki training Center in Japan. During the course of this PhD research, the researcher undertook eight (8) projects, eighteen (18) studio activities and in the process created five hundred and thirty one (531) knitted fabrics and garments.

The researcher critically reviewed and compared a variety of different design development processes that she had trailed by analyzing her notebooks, the projects' knit data and the emails exchanged in the different projects. In parallel, the researcher created maps of processes and workflows for different knitwear design and development activities (see Chapter 5). Process mapping analysis was used to identify and make changes in practices, roles, and workflows to improve the garment development process.

At the early stages of the research, the focus was simply to bridge the gap between the knitwear designers, knitting machine technicians, and knitting machine operators in the garment prototyping system to the point of *1st sample* stage. As the research progressed, the focus of research evolved into the development by the researcher of a new integrated high-fashion computerized seamless knitwear design process. The researcher has called this an 'integrated design process' because the knitwear designer integrates the three roles of knitwear designer, knitting machine technician and knitting machine operator.

This new integrated knitwear design process involves only the knitwear designer for all design processes up to and including the creation of *1st sample* fabric or garment (Figure 98).

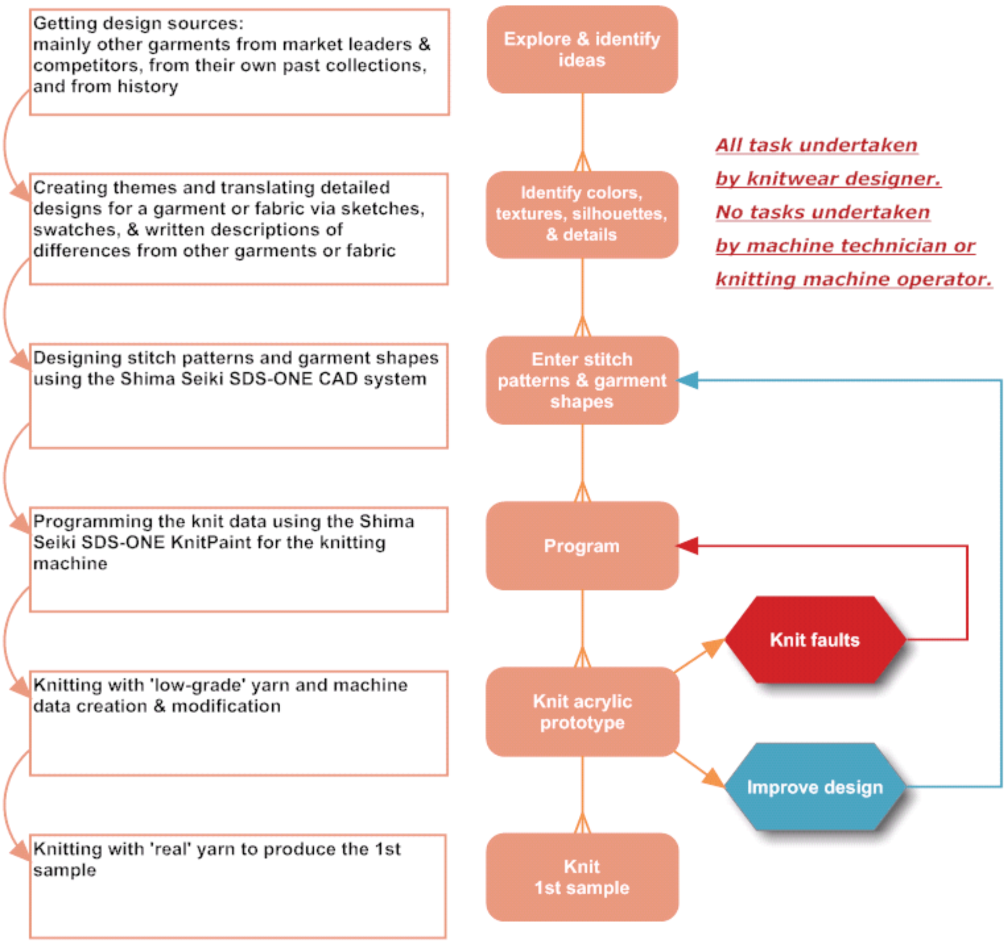


Figure 98: Workflow for the new integrated fashion knitwear process to the point of *1st sample* stage

In practical terms, this integration of all activities under a single expert, enables skill specialization with all its benefits. The task foci of the knitting machine technician and knitting machine operator are in this new integrated process delayed until after the design work has been undertaken and focus instead on the optimization and production of fabrics and garments after the *1st sample* has been produced successfully. Figure 98 shows the practical details of the workflow process the researcher identified and successfully tested for *1st sample* design and production using the Shima Seiki WholeGarment® knitting system.

This new integrated high-fashion knitwear development process eliminates many unnecessary steps that previously also involved the machine technician and knitting machine operator. This helps make the knitwear design and development process more efficient and effective.

This new integrated knitwear design and development process opens the envelope for creative high-fashion knitwear design in many ways, some unexpected. For example, it opens up the opportunities for high-fashion knitwear designers to use a much wider range of yarns. Manufacturers restrict the use the types of yarn to those best suited for the knitting machine regardless of the knitwear designer's will. This significantly restricts the knitwear designer's yarn choices and can present many problems when knitwear designer decides to change stitch pattern(s) after creation of the acrylic yarn prototype garment. Use of a different stitch pattern or different sequences of stitch patterns creates different garment shapes - even with exactly the same type of yarn (see Creating high-fashion garments silhouettes using stitch structure combinatorics in Chapter 7). Using the new integrated computerized seamless knitwear design and production process, the designer has the freedom to experiment and identify ways of using a much wider range of yarns and knit structures resolving any problems in the course of developing preliminary *1st samples* by self-directed experimentation.

Carrying out the projects and process mapping of activity and design, analyses of the projects and other studio activities also resulted in the identification of other contributions to knowledge, design practice and design methods.

Research Question 3: Can this new approach be taught?

To enable high-fashion knitwear designers to be able to develop garments to the point of completion of *1st sample* using Shima Seiki WholeGarment® knitting technology, changes need to be made in the curricula used for educating Fashion and Textile Design students and knitwear designers.

During the research, the researcher tested the teaching and learning of her new approach six times: two courses to university fashion students, two seminars with TAFE students and staff, a seminar/presentation to fashion designers, and the researcher’s own autodidactic learning. These five courses and seminars, and the personal learning experiences of the researcher, confirmed that teaching and learning her new integrated high-fashion knitwear design process using computerized seamless V-bed knitting technology was unproblematic for fashion students at university and TAFE, and practicing high-fashion knitwear designers. From the experiences of delivering these courses and seminars on the use of computerized seamless V-bed knitting technology, the researcher developed but has not yet trialed a new curriculum for a short studio course (see Figure 132 in Appendix 7).

A typical introductory class conducted by the researcher with tertiary Fashion and Textile Design students always included the following three experiences:

- View virtual simulation of knitted fabric or WholeGarment® on the SDS-ONE® CAD system. Comments: Most observers are amazed by this function. Have one of students choose a stitch pattern or a pre-registered garment shape from the CAD pattern library (800 variants) and have the student select color and a type of yarn and see the garment knitted virtually;
- View the knitting machine in motion. Comments: After a few minutes, people typically lose interest. Experience showed that students prefer to see a garment almost finished knitted and be completed and drop into the garment catch tray; and
- Use the Shima Seiki Help Animation files while learning the mass-market WholeGarment® knitting approach. Comments: Shima Seiki offers many Help Animation files on the basic knitting technology and standard workflow. The ease of use of these Help Files is variable and sometimes limited.

Changes identified intended to enhance the quality of the sessions:

- Each student reviews the CAD pattern library with an expert who knows the knitting system;
- Sessions in which students can see and feel knitted fabric swatches of the stitch patterns in the library of the CAD system. From experience, most students find it hard to imagine what a CAD generated (virtually knitted) image would look like when knitted;
- Have as a pre-requisite that practical knitting-related skills are needed for anything other than superficial courses. Appropriate practical skills include: hand/machine sewing, hand knitting, and crocheting. Experience in hand-framed machine knitting is desirable;
- Use an appropriately sized teaching space to teach (say) 24 students. The current research studio is too small for this;
- Arrange students to be pre-prepared for undertaking the course. Computerized seamless V-bed knitwear design and manufacture is considerably more complex in relatively restricted time access of each student to the knitting system makes it critical for students (and educator) to be well-prepared and for the education to be efficient;
- Consider preferentially targeting postgraduate students;
- Emphasize the differences between prototype garments programmed and knitted using 'easy to knit' yarn (typically acrylic yarn) and 1st samples programmed and knitted using the final yarn intended for production. Significant changes occur in shape, size, drape and texture between the two yarns when knitted with the same programming and machine settings; and
- Increase the level of education in knitwear design and conceptualization in tertiary technical institutions. If a soon-to-graduate student from a technical institution has an opportunity to work with an experienced designer on a one-to-one basis as a sample developer, it would be beneficial for both. Internship arrangements may be more desirable than work experience which has negative connotations among some students.

New additional role for high-fashion knitwear designers: the high-fashion 'designer-interpreter'

A new professional 'role' in high-fashion design emerged during this research. The researcher has coined the term 'designer-interpreter' to refer to this role. The 'designer-interpreter' is someone who has the professional expertise of a high-fashion knitwear designer and in addition can interpret and align the high-fashion knitwear concepts of others with the potential of the computerized seamless V-bed knitting technology. The 'designer-interpreter' is a high-fashion knitwear designer, who also programs the computerized seamless V-bed knitting machine and operates it. The three roles of designer, programmer (machine technician) and knitting machine operator become combined into one position.

This provides an important bridging role of the 'designer/interpreter' as a collaborator with other high-fashion knitwear designers whose education has been limited in its opportunity for them to learn the potential and skills of computerized seamless V-bed knitwear design. The 'designer-interpreter' can facilitate the use of the computerized seamless V-bed knitting technology by high-fashion knitwear designers and students who have not yet acquired the skills in using the technology themselves. This is very different to the previous use of a machine technician in this role because the high-fashion designers are collaborating with a skilled fashion design professional who completely understand the economy of production as well as aesthetics of fashion garment designs.

Resolution of the research problem

During the course of work, the researcher undertook investigations to address and resolve the research questions described in Chapter 1 through the process of answering the research questions from Chapter 2. This approach enabled the researcher to identify and successfully test the new integrated high-fashion knitwear design and manufacture process described earlier using the Shima Seiki WholeGarment® knitting system.

This empirical testing of the new integrated process demonstrated that a high-fashion knitwear designer with additional training is able to produce *1st sample* across a variety of semi-commercial fashion projects without any intervention of knitting technologists (knitting machine technician and knitting machine operator) and with minimal technical support. In other words, this new integrated process model offered knitwear designers the opportunity to develop fabrics and garments using their expertise of high-fashion knitwear design without the problems currently widely identified in the field between designers and technologists. In addition, as described above, this also resolved problems in the workflow of knitting machine technicians and knitting machine operators.

Viewing the research and research outcomes in terms of Memetics

The researcher has viewed the research problem in terms of it being a problem within a socio-technical system. Systems analysis offers other perspectives on analyzing the same phenomena. Another systems viewpoint that provides further insights and confirms the direction of the research is that of Memetics.

The findings of the research can be seen in Memetic terms as an evolution and propagation of a new meme of high-fashion knitwear design using computerized seamless knitting technology. In Langrish' terms (1999; John Z Langrish, 2004), the researcher started with a 'Selecteme' of 'how can fashion designers be better included in using the Shima Seiki WholeGarment® knitting machine to create high-fashion garments?'. She then devised an 'Explaneme' that explained the main issue of the research problem and potential ways of solving it, for example, process maps, the literature analyses of Chapter 3, the collected data reported in Chapter 7, knitting tests in projects, and teaching reflections. Together these resulted in 'Recipemes': the outcomes of analyses and conclusions in this chapter, which are theory recipes describing how high-fashion knitwear designers and knitting technologists can work together better by using the new integrated knitwear design and manufacturing process; and how fashion designers can be taught via a new curricula: a second 'Recipeme'.

Implications

This PhD research resulted in contributions to knowledge in the field of high-fashion knitwear design and manufacture. It also provided insights for improving both high-fashion knitwear design practices and design education for high-fashion knitwear designers relating to the use of computerized seamless V-bed knitting technology. The research identified opportunities for new design practices and for future research that are described in more detail in the following chapter.

Contribution to knowledge in knitwear design field

The theoretical analyses and empirical experimentation of this research led to three main contributions to knowledge in the computerized seamless V-bed knitwear design field and from this followed several minor contributions to knowledge.

The three main contributions to knowledge were:

- Identification of a new integrated design and production process for high-fashion computerized seamless V-bed knitwear systems up to and including the creation of 1st sample. This new integrated high-fashion knitwear design and manufacture process addresses the research problem as defined in Chapter 1. It is undertaken solely by a fashion knitwear designer and does not require input from knitting machine technicians or knitting machine operators until after 1st sample is created. This new process provides the basis for answering the first two of the research questions;
- The research established the feasibility of a new industrial design profession: a 'post-industrial craft-based one-person-production system' that the researcher has given the name knitwear 'designer-interpreter'; and
- Using the approaches developed in this research significantly increased the easily accessible creative solution space available from the computerized seamless V-bed knitting technology. The use of two specially developed garment template packages for shapes and details alongside the existing pre-registered garment shapes and the extension approaches enabled by the new design methods for advanced shaping and manipulation offer a very large number of combinations of unusual garment shapes, textures, and garment details suitable for use by high-fashion knitwear designers.

These contributions to knowledge potentially offer significant benefits across a wide variety of situations in the international high-fashion knitwear industry. The underlying analyses extend to other knitwear technologies besides computerized seamless V-bed knitting. Areas in which they potentially offer industry wide benefits include: improved design output from computerized seamless V-bed knitting systems; 'Fast Fashion'; *1st sample* design, manufacture and testing; reduction in time to market of products; reduction in design costs; reduction in manufacturing costs; and increases in the creative solution envelope for high-fashion knitwear design.

These two contributions to knowledge also led to the identification of several related findings that inform improvements to professional and industry design practice and design education in the use of computerized seamless V-bed knitting technology in the high-fashion knitwear arena. The main areas are:

- Design education;
- New high-fashion ‘designer-interpreter’ role;
- Post-industrial fashion design craft atelier;
- Improve factory training; and
- Improvements to the computerized seamless V-bed knitting technology for high-fashion design.

A variety of other useful smaller insights emerged at different points throughout the thesis in Chapters 7, 8, 9, 10, 11, and 12.

Contributions to fashion design education

The insights gained from the research exploring whether this new approach can be taught can be seen in terms of a feedback loop ‘Training>Practice>Refine>Teach’ (Figure 99) which echoes the classic Shewart cycle used in socio-technical systems analysis.

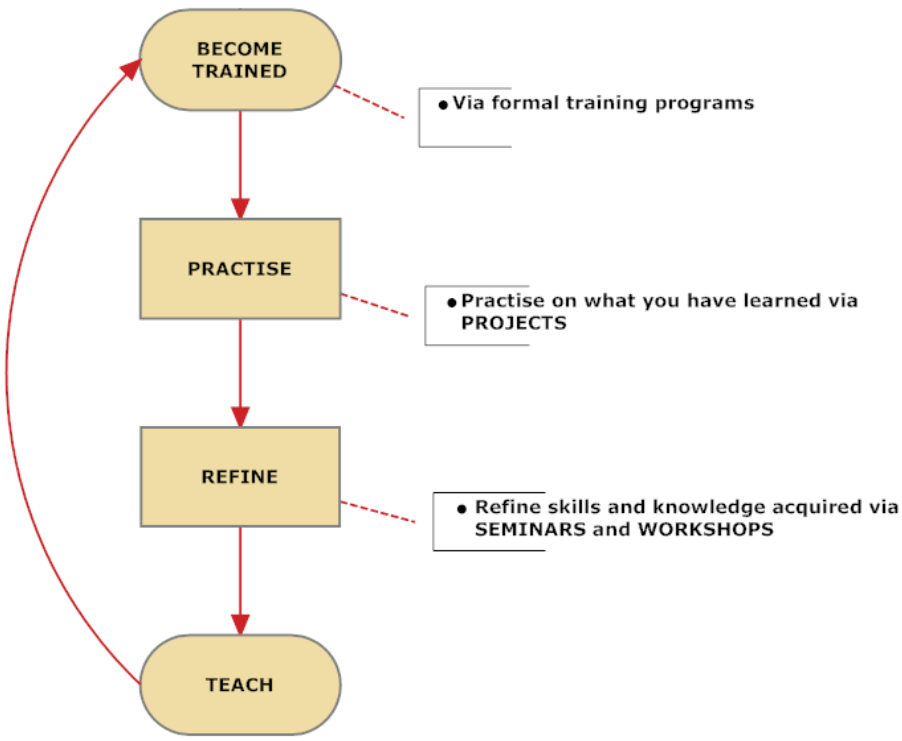


Figure 99: The workflow of learning to extend high-fashion knitwear design skills to include computerized seamless V-bed knitting.

A collection of contributions to fashion knitwear design education were identified as a result of developing and testing curricula for educating fashion designers in the researcher’s new integrated design process for the use of computerized seamless V-bed knitting systems. The curricula and outcomes were described earlier in Chapter 12.

Contributions relating to design education were:

1. Development and testing of new curricula for education programs suitable for fashion designers for training in Shima Seiki WholeGarment® knitting. These curricula would be expected to apply for most computerized seamless V-bed knitting technology regardless of machine manufacturer.
2. Conventional knitwear fashion education can easily be extended to include short programs training students to design garments using computerized seamless V-bed knitting technology.
3. Understanding the current limitations of computerized seamless V-bed knitting production system remains limited among fashion designers and fashion design educators.
4. Prototyping to creation of *1st sample* is important for students to understand the difference between on-screen garment development and final garment as programmed and knitted using computerized seamless V-bed knitting systems.
5. Computerized seamless V-bed Knitwear design involving specialist yarns requires the yarn issues to be considered at the outset.
6. The use of computerized seamless V-bed knitting systems can be effectively linked to design work of fashion students involved in post-garment embellishment via hand knitting, crocheting, and hand-framed knitting.
7. Tertiary Fashion and Textile Design students can be trained in a short course to design non-conventional extreme garment shapes programmable using S•Paint images on the Shima Seiki WholeGarment® knitting system. This would be expected to be replicated on other computerized seamless V-bed knitwear systems.
8. Working at a scale of ¼ of women's size 8 is an efficient and cost effective way for developing shape prototypes using computerized seamless V-bed knitting technology.
9. Miniature garments can be unusually eye-catching when made for public display by students. Designing miniature garments is an effective and efficient teaching tool for teaching tertiary Fashion and Textile Design students about computerized seamless V-bed knitwear design and production.
10. Knitted garments suited to performance dancewear are a useful student project but require several additional considerations over and above those normal in fashion design. Careful consideration needs to be given to providing stretch in appropriate locations and in finishing work. For example bind-off edge finishing can limit movements and slits in knitwear for arms and legs needs to be managed carefully to avoid chafing, tearing and limitations to movement. The use of reflective wools appears to be important in dancewear because conventional wool fiber, in general, absorbs light, rather than reflects it. This lack of light reflectivity makes wool performance wear appears less sophisticated. The new hydroxide

treated mercerized wools offer a potential solution (Australian Wool Innovations (AWI), 2010).

A new high-fashion 'designer-interpreter' role

The research identified a new professional high-fashion knitwear designer role which the researcher has called a fashion 'Designer-Interpreter'. This role is as a co-designer with other fashion designers by which the 'designer-interpreter' acts both to guide the design of new garments to make use of the new creative potential offered by computerized seamless V-bed knitwear technology and also to interpret more conventionally developed fashion designs for production by computerized seamless V-bed knitting machinery.

This role may be a temporary phenomenon due to the lack of education of fashion designers in computerized seamless knitwear design and may disappear as increasing numbers of high-fashion knitwear designers are trained in using computerized V-bed knitwear design and manufacturing systems. It is, however, a significant role as of now because the role bridges the

Post-industrial fashion design craft atelier: the 'craft-based one-person high-fashion knitwear factory'

The researcher's new integrated design and manufacturing process for computerized seamless V-bed knitting provides a basis for a 'craft-based one-person high-fashion knitwear factory'. In effect, it provides the potential for a post-industrial fashion knitwear craft opportunity in both Fashion Design and Art fields. The researcher is grateful to an examiner of this thesis for this deep and useful insight.

The empirical aspects of this research demonstrated that the new integrated computerized seamless V-bed knitwear design and production process using Shima Seiki WholeGarment® systems are robust enough to be used in rapid prototype development of high-fashion garments for shows and collections. The knitting machine itself is not as delicate as many people (including the designers and technicians) expect and this enables extreme experimentation appropriate to high-fashion design explorations.

Improving manufacturer training for fashion designers

A minor contribution emerged from the research in relation to improving the manufacturer's training. The research identified the need for manufacturer's training to help bridge between the professional cultures and practices of fashion designers and the more technical culture of those providing the teaching. In addition, language barriers between tutors and students appear to be less problematic when the person undertaking the teaching is trained in fashion design.

Insights relating to computerized seamless V-bed knitwear design and manufacture technology

The following contributions to improved design of computerized seamless V-bed knitwear technology emerged during the research as a result of the researcher's reflections on the high-fashion design practices using this technology of herself, other fashion designers and students. The research was conducted using a Shima Seiki computerized seamless V-bed knitting system. The researcher identified many opportunities for Shima Seiki to make the

KnitPaint, S•Paint *software* and knitting machine operation more user-friendly for high-fashion designers.

1. Identification of the need for an improved programming interface for computerized seamless V-bed knitwear design development that is more culturally and aesthetically matched with the skills and ways of working of creative high-fashion knitwear designers (this aligns with the findings and research of Claudia Eckert and her colleagues (Eckert, 2001; Eckert, Cross, & Johnson, 2000).

2. Identification of the need for new high usability software to enable creative/high-fashion knitwear designers to directly program computerized seamless V-bed knitting machines at a stitch-by-stitch level. This is different to the current approaches for semi-automatic production of program code. An example would be the ability to automatically transfer color vector diagrams directly into the knitting machine code.

Future Research: sustainable high-fashion knitwear

In addition to the findings of this PhD research, the research revealed new opportunities for high value research advancing the high-fashion potential of computerized seamless V-bed knitting. This section identifies four significant future research possibilities and enumerates other possibilities identified during this PhD including several new directions in sustainable high-fashion knitwear ***relating to new garment development processes and new knitted garment product types:***

- Research into the development of new models of high-fashion knitwear garment construction using computerized seamless V-bed knitwear design and manufacturing technology, combined with hand craft knitwear and fashion design techniques;
- Research into the potential solution space of design of multi-style/multi-fit knitwear using slash and slit, i.e. geometrically defined knitwear that can be worn in different ways;
- Research into opportunities offered by combining computerized seamless V-bed knitting and new types of yarns (for example, fine merino wools, mercerized merino, dual taper-ended soft-feel wools, and other new natural derived yarns); and
- Research into using deliberate failures in wool garment post-finishing approaches (e.g. over-felting and high fabric shrinkage) as an artistic modification to computerized seamless V-bed knitwear design and manufacturing technology outputs.

Research into new models of knitwear construction: combining hand craft and computerized seamless V-bed knitwear design

Further research in this area is indicated to investigate best practices for integrating computerized seamless V-bed knitwear design and manufacturing technology knitting with hand craft techniques. Computerized seamless V-bed knitwear design and manufacturing technology knitting can be integrated with traditional hand craft knitting to produce their own unique features as shown in Figure 100.

Figure 100: Computerized seamless V-bed knitwear design and manufacturing technology knitted tubes with post-embellishment suitable for development in hand-framed knitting. Source: (DAFWA, 2008)

The development of interesting knitwear designs can be accelerated. Simple garment shapes can be created using computerized seamless V-bed knitwear technology and post-embellishment can be done by hand knitting, crocheting, a combination of both or using many forms of textile art such as embroidery, feltmaking, needlework, patchwork, sewing, weaving, and knotting to enhance the look of machine-knitted garments, making them more desirable to customers.

Multi-style multi-fit knitwear using slash and slit with tubes and flat panels

A second opportunity for future fashion design research involving computerized seamless V-bed knitting technology is the geometry and garment structure of multi-style multi-fit knitwear using slashes and slits with tubes and flat panels.

These are designs that can be worn in different ways thus increasing their versatility. The different ways that the garments can be worn depend on the geometric configuration of the garment. Garments based on tubes with slashes and slits can be worn in a variety of ways dependent on the tube(s) and location, number and size of slashes and slits. The researcher has undertaken preliminary investigations and found that even simple combinations offer many different opportunities for multi-style and multi-fit garments. Applying the slash technique to a flat panel create more garment design options. For example, a knitted fabric with six horizontal slashes can be worn in at least six different ways as shown in Figure 101.

Figure 101: Six different ways of wearing a six-slashed flat panel

The possibilities for the six different ways of wearing the garment were led by the six slashes, which appear as garment apertures when the garment is worn on the body. Each of the sets of holes relate functionally to six culturally acceptable 'exposable' body areas (Figure 102).

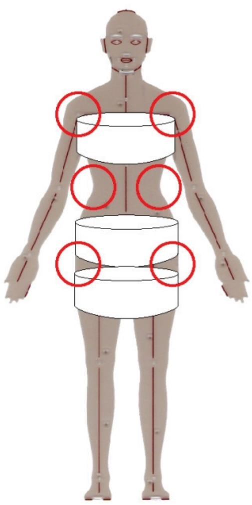


Figure 102: Six culturally-acceptable exposable body areas

This fashion concept can be extended using computerized seamless V-bed knitting design systems by ‘attaching’ additional garment elements or tubes. This multi-style knitwear can also be extended into the season-less realm if made from appropriate material that is comfortable next to the skin - e.g., soft and light ‘next to skin’ wool.

Season-less knitwear

A third avenue of future research is the opportunities for season-less high-fashion knitwear made available by the increased envelope of the high-fashion design ‘space’ due to the new design and manufacturing opportunities from computerized seamless V-bed knitting systems combined with new natural knittable yarns with soft feel, excellent drape, easy care and good environmental pedigrees.

Season-less garments can be defined as clothing that people can wear regardless of the climate or time of year. This concept of ‘season-less’ garments with its ‘trans-seasonal look’ has become the subject of strong of interest in the fashion industry across all garment types. It has significant potential commercial benefit for garment retailers and manufacturers because it acts to reduce the number of different types of garment in stock at any time and reduces garment waste.

This season-less trend potentially more positively benefits the knitwear industry more than other garment industries because of knitted fabric’s performance, wrinkle resistance and recovery, and its open structures. Knitted fabrics are considered to be ideal travel fabrics: they do not wrinkle to the extent that woven fabrics do (Hatch, 1993, p. 346). The open structures of knitwear are ideally suited for providing thermal insulation in still air conditions; equally, they provide more air permeability in hot conditions (Hatch, 1993, p. 347). Knitted fabrics are more adaptable than woven fabric in coping with heating or air conditioning and the difficult garment functionality required of sports performance. There are already a handful of classic styles that provide a starting point for season-less knitwear such as the thin bolero, cardigan, and wraparound, shrug. Moreover, their resistance to the fashion industry’s built-in obsolescence, of usually one to two seasons (either Autumn/Winter or Spring/Summer), may break old world fashion conventions and bring a new fashion paradigm which can be more suitable to the global climate change.

Research into using post-garment finishing errors as fashion design techniques

Another significant future knitwear research involving computerized seamless V-bed knitting technology is the use of felting/fabric shrinkage in seamless garments to provide an additional layer of attractive garment shaping and detail.

Felting can play a valuable role in knitwear design when practised on purpose. Unexpected and unique fabric textures and attractive garment shapes can also be created using felting techniques, which are normally regarded as a ‘failure’ of post-garment finishing. Galeskas (2003, p. 17) regarded shrunken knitting as usually a cause for sadness and pointed out several common changes resulting from felting. All of these have potential high-fashion and artistic potential:

- Felting results in combining multiple yarns or colors in ways that result in unusual outcomes and react very differently;

- Fiber migration can happen in which dark fibers released during agitation of the felting process become felted into the light sections of the item and alter its color;
- In a square piece, plain stitches shrink more in length than width. Also different stitches and patterns shrink differently; and
- When the length of a garment greatly exceeds the width, the weight of two ends stretches the center of the long piece during the felting process and vice versa.

In addition, different processes of fleece affect the way that yarns felt. Knits on the same gauge with the same number of stitches can result in differences in size and proportions after felting. The center of a piece always felts more than the edges. Consequently, the edges are distorted (Figure 103).Many commentators such as Galeskas (2003, p. 15) have claimed these changes from felting present a problem in many designs. Viewing them differently, these changes can be treated as a useful design details and opportunities. For the creative fashion design professional, test-felting of designs can result in more design ideas; even though the results at first might seem disastrous.

Figure 103: Example of felted wool with spontaneous reshaped edges

Other research opportunities

During the PhD, several other possibilities were identified for future research including research into:

- Commercial potential of fabric and garment design modules kits;
- Deliberate use of knitting defects as fashion design methods;
- Textualizing indigenous art using computerized seamless V-bed knitting technology;
- Value of 24/7 live technical help-desk for fashion knitwear designers;
- Commercial potential of multiple 1st samples;

- Development of new form of post-industrial high-fashion knitwear craft design;
- Improved methods of knit data and garment data file management;
- Development of new fashion knitwear course curricula;
- Potential for manufacturer-based short training seminars for fashion designers;
- Potential improvements to Shima Seiki's training in Japan for high-fashion knitwear designers;
- Improvements to usability of *KnitPaint* software for fashion designers;
- Development of web-based training in computerized seamless V-bed knitwear programming for fashion designers; and
- Improved course curricula for professional high-fashion knitwear designers using computerized seamless V-bed knitwear design and manufacturing technology.

Summary of PhD Research

This PhD research has resulted in the development of a new industrial integrated high-fashion knitwear design process together with a suite of design methods that have been tested both on real world semi-commercial projects and in the education of design students and professional fashion designers. This new approach developed and tested by the researcher fully includes fashion designers into the design process of fashion knitwear developed using computerized seamless V-bed knitwear systems. Simultaneously, it significantly extends the creative design envelope of computerized seamless V-bed knitting systems, which is particularly significant in the field of high-fashion knitwear. This new integrated process results in fashion knitwear designers undertaking all of the tasks of design and manufacture up to an including the creation of the *1st sample*. It results also, therefore, in the elimination of the roles and tasks of knitting machine technicians and knitting machine operators in the fashion design process to this point of *1st sample* stage. Thus, it simplifies and removes many sources of problems in the design process workflow and this first stage in manufacture.

In a craft, rather than industrial context, this research demonstrated the feasibility of the use of computerized seamless V-bed knitwear systems for 'post-industrial craft' as a one-person-production system'.

In addition, the researcher developed and tested ways of teaching this new integrated design approach for fashion knitwear designers. The researcher trialed several educational approaches including the development of a new fashion role that she has called 'designer-interpreter' in which a fashion knitwear designer experienced in using computerized seamless V-bed knitting systems acts as an intermediary 'design-interpreter' for other fashion knitwear designers who have not yet learned to use this technology.

Future research avenues were also identified.

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Appendices

Appendix 1: Reflections on each project and its applied process mapping

- Project 1: ‘Design for Comfort’
- Project 2: ‘Wagin Woolorama Ambassador 2007’
- Project 3: Cone-shaped artifact
- Project 4: Tube sessions 2007 at Curtin University of Technology
- Project 5: Knitwear design using Merino Soul's yarn
- Project 6: Professional Practicum 390 at Curtin
- Project 7: Dance performance at the Livestock Updates 2008
- Project 8: Tube sessions 2008 at Curtin University of Technology
- Afterword: Personal retrospective field experiences with a group of people in Korean fashion industry

Project 1: 'Design for Comfort'

Reflection on the project

In September 29, 2005, I was invited to a session at the Department Agriculture and Food Western Australia (DAFWA) to introduce the Shima Seiki WholeGarment® knitting system. My lecturer, the senior project coordinator, had mentioned the possibility of my being involved in the project. A wool scientist with DAFWA arranged the session. I also met with other DAFWA staff members. It was interesting to hear the wool scientist say that the work flow of the knitting system would have been much simpler and easier if the system had been designed by an Australian. The wool scientist acknowledged there was a cultural barrier in understanding the whole mechanism of the knitting system. She found it difficult to understand the mechanism of the machine because it is based on the thinking patterns of Japanese people.

In January 23, 2006, I joined the 'Design for Comfort' team as a research student. Even though I had wanted the chance to work on the machine for a long time, I had no previous knowledge of it.

My task was to design and create novel textiles for five Western Australian (WA) fashion/textile designers using WA merino wool and the Shima Seiki WholeGarment® knitting system at DAFWA. The wool scientist, who had trained briefly with Shima Seiki in Japan, gave me three lessons. After that, attending to the needs of five designers was my responsibility, and I devoted myself to learn the knitting system.

People involved in the project did not seem to have high expectations, but I did. Getting to know the machine and its software was a challenge, but surprisingly, I found it relatively easy to start to use it, and I managed to produce fabrics on the machine. This was before I went for the first formal training at Shima Seiki in Japan. The knitted fabrics that I created and knitted were later made into garments by the five WA designers and dressed the fashion models at the official opening ceremony of the AWI 7th World Merino Conference at the Merino Innovation Day at Egerton, WA on July 12, 2006.

The five WA fashion designers' works for the 'Design for Comfort' were Aurelio Costrarella, Rebecca Paterson, Megan Salmon, Louise Snook, and Melissa Yap. They were understanding and cooperative, and I prepared initial samples before I met with each of them. The senior project coordinator pre-selected knitted fabrics for each designer because she knew the designers well.

When I met with each designer, reactions were varied. Aurelio and Rebecca picked designs from pre-selected samples. Rebecca was a little more specific than Aurelio about what she was keen on. To my surprise, Aurelio had no specific requests. He simply chose a few samples from whatever I had prepared. I still wonder whether it was his work style, or that he had no expectations at all.

On the other hand, Megan, Louise, and Melissa were precise and explicit about what they asked for. Megan had copyright over work of a famous indigenous artist. She wanted me to simulate the artist's drawings as knitted fabrics. She gave me photocopies of his work along with his book. It was challenging to me, even though I had done similar work for twelve years. I knew the correct work flow of the job on the knitting system to create the fabric, but I did not know how to operate the incorporated CAD system for that function. Luckily, there were no set time constraints, in contrast to working in the industry. When I completed the fabric on the knitting machine, it gave me such confidence. Louise asked for similar work to Megan. She wanted simulations of natural sand flow. She emailed me photos of sand on a Western Australian beach. I could easily do this, because of my trial and error process for Megan's request. Melissa expressed the most interest in the project and saw the project as a professional career opportunity. She initially chose a sample from the pre-selected samples, but I had to go into much more detail to make it look like a 'spontaneously produced fabric'. It did not, however, capture the carefully planned flaw look because of over-felting. Working with her ideas offered me the opportunity to gain solid preliminary knowledge of the Shima Seiki knitting system.

The design process for the project started from the wool scientist's email to the senior project coordinator asking how many fabrics needed to be developed for each designer. And then, the senior project coordinator's reply followed:

> *… I discussed the fabric development with Sooyung this morning and recommend that the focus be on developing ONE simple, but exclusive, fabric with each of the designers. Total of five only fabrics based on basic manipulations of structure that are generally agreed on as being 'simple and do-able'… The initial meetings with the designers will need to be held in the week of 13th Feb ... This will give Sooyung a couple of weeks to explore basic samples of the ideas for presentation at these meetings …*

The wool scientist was worried about the timeline, which then only allowed us (herself and myself) three days' training on the knitting system. The senior project coordinator mentioned the possibility of postponing the meeting with the designers to the end of February instead of meeting them on February 13. The senior project coordinator, however, pointed out it would mean I had much less time to develop the fabrics for each designer. She finally suggested having a more general first meeting on February 13, and then going back with some samples for responses at the beginning of March.

My PhD enrolment commenced at the same time. My PhD supervisor at that time, asked me to keep two diaries, one for keeping track of events and the other for design development.

On February 2, I emailed the senior project coordinator about my concern over the colors of yarn in stock. The wool scientist told me that there were few options to choose from. Some yarn was obtained from a stockist in Melbourne[5]. They were far away from being 'fashionable', and were 'boring' in a fashion sense. I proposed giving each designer a choice of selecting a preferred yarn because giving them more choices might end up creating an obstacle to production, such as frequent yarn color changes. I made it clear I would do my best to produce the fabrics that satisfied the designers' needs. If impossible, I would let them know in advance.

A comforting email from the senior project coordinator came the next day. We could talk with the designers and see how we would deal with this. Her message was that as long as the designers understood the situation, and we had a good communication process that there would not be too many problems… It was a big day for me. I managed to produce fabric with no defects for the first time. I phoned the senior project coordinator at home to share the news. I felt relieved and so did she.

The senior DAFWA researcher with the Wool Desk at DAFWA requested information on yarn for the project. I contacted a sales manager at Cheil Industry in Korea via one of my previous colleagues and asked for the sales manager's help. The company is known for its high quality yarn. He offered me a color swatch book under the condition that someone

[5] The knitting machine at DAFWA, like all other types of knitting machines, works on very limited range of yarn that suits the type of the machines; thus, it is hard to get suitable yarn for the machine in Australia. There were only six computerized knitting machines at that time in the state. There were, consequently, very few yarn stockist that carry the type of yarn for the type of the knitting machines at DAFWA.

had to pick it up at his office and mail it to me overseas to give it to the senior DAFWA researcher.

On February 14, the senior project coordinator emailed me regarding information about yarn. On the following day, another email came asking whether I knew about the new yarn made from WA wool fiber. She emphasized that it would be great for the project because it would help the Design-for-Comfort team to integrate WA materials into the project. My reaction was that this should have been planned from the beginning. I believed my involvement was not planned in the beginning either. I guess things happen and change regardless.

While making the initial fabric samples for the first scheduled meeting with the designers, the senior project coordinator said the fabrics look more interesting due to the irregularity and even holes caused by programming errors. She commented that people tend to associate regularity of surface design with something machine-produced and, therefore, less valuable than hand-produced fabrics. This idea was new to me. In my experience, the fabric needed to be flawless for high-fashion.

The senior project coordinator was right. The five designers did not mind imperfections in the fabric and said the defects were exciting. It has been two years since I completed the Design-for-Comfort project. And I still feel uncomfortable producing imperfect fabric.

Designer 1: Aurelio (Ray)

I had met Ray once when I was an undergraduate at Curtin. Each of us was asked to bring a few of our own best samples and Ray then would go over the samples and give feedback. When it came to my turn, he went over my sample swatch books, all created by a hand-framed knitting machine, and picked the one I had the most difficult time with. It was a combination of very heavy coarse wool yarn and sewing thread. He looked impressed. It offered me an early chance to sense his preferences.

When I visited him at his studio, he sounded like he could go with anything given. He had no specific requests. I had prepared a few fabric samples for him, but his conduct made me feel reluctant to show him. The senior project coordinator suggested I show him the swatch which was ‘full of mistakes’ (Figure 104) made accidentally because of my initial limited skills on the knitting system. Somehow, it was knit-able even though the programming as well as the machine setting was completely wrong. Ray liked it very much. I did not tell him how many knitting needles had been broken and how much extra yarn I needed to create that kind of look. Later, I found out I was fortunate that I could produce such fabric on the knitting machine without damaging the machine. I was not aware of the potential drastic consequences.

Figure 104: The fabric, ‘Full of Mistakes’. Source: (DAFWA, 2006)

Designer 2: Rebecca

Rebecca has a charisma that intimidated me at the beginning, but soon I felt comfortable talking about the project. Preceding the meeting, I had prepared a few simple samples she might be interested in. She was keen on a sample based on stitch pattern combinations. More of knitting needle moment of transfer and missed action were involved in the fabric design than knit action. The fabric was expressed irregularly and had an airy texture even though its CAD design on *KniPaint* software was wholly based on regularity. I remember she kept saying it would be perfect for her ‘tutu’ look. When she felted the fabric later, the open structure shrank and gave rise to the ‘jiffy’ look (Figure 105).

Figure 105: The 'Jiffy' look of the developed fabric. Source: (DAFWA, 2006)

Designer 3: Megan

I had met her and her business partner Steve at the session at DAFWA to introduce the Shima Seiki WholeGarment® knitting system. Steve seemed amazed when the wool scientist explained what the knitting system could do. I remember his comment that a designer who could use the system would be a most sought-after person!

On March 3, Megan was prepared for what kind of fabrics she needed. She gave me several photocopies and the original book of the work of Jimmy Pike, a renowned Aboriginal artist. She wanted to have an organic look on the surface design of the fabric. The images were perfect on which to develop that style of knitted fabric. She was able to make this request because she was at the introduction session with me and understood the machine's potential.

This was the most challenging task. I knew the right work flow on the knitting machine to develop the design theoretically, but I had not had a chance to test the system for that purpose. I must admit my previous knitting industry experience was a big help. I had worked on several different Apparel CAD systems since 1994. Fortunately, her first sample was created without much frustration. One of fabrics developed for her was so uniquely different that she applied the design to her own line produced in China (Figure 106).

Figure 106: An artist's work in fabric form. Source: (DAFWA, 2006)

Designer 4: Louise

Louise visited me at the knitting studio. I explained how the design development process for each designer was to work. I knew she had expertise in felting and guessed she would try felt experimentation with the supplied fabrics. I asked her to send me images for the design development and gave her a piece of wool cloth with which to experiment. She sent me four rippling sand photos (Figure 107) along with her feedback on the wool cloth: it felted beautifully and its thin thick variations were appealing. She was so clear in her email, that I developed the fabric for her quickly (Figure 108).

Figure 107: Images of rippling sand. Source: (Fletcher, 2003)

Figure 108: Realization of combined sand images. Source: (DAFWA, 2006)

Designer 5: Melissa

Melissa and I had something in common: we were both the senior project coordinator's students and both loved hand-framed knitting machines. She was pleasant and easy to get along with and was also enthusiastic about the design development. Since she knew about knitting, we could go into great detail, even though it was our first official meeting for fabric development. Melissa wanted a geometric open structure that she could play with when felting and also wanted to try a mix and match style both in knitted and woven fabrics. Most of my time was spent in attempting to transform the geometric and machine-produced appearance of one of the pattern library designs into something else: something that did not look carefully programmed, but would look like it had been produced spontaneously.

I was hoping for serendipity to play a part. It did when the fabric finally came to life, it became my favorite. It was attractive (Figure 109) and was also interesting because there could be more or bigger holes in the fabric, if it was pulled in any direction.

Figure 109: Re-establishment of a geometric stitch pattern. Source: (DAFWA, 2006)

Melissa's design, a short dyed jacket, was interestingly composed of a combination of several long strips (Figure 110) so that it could have been further developed as a prototype. It offered endless possibilities of garment silhouettes.

Figure 110: Jacket made from series of strips. Source: (DAFWA, 2006)

Applied process mapping of the project

Table 12 profiles the project process initially derived from the investigation of emails and the printouts of the emails. The method, 'verb + noun + qualifier' combination, though developed for the military and also not applicable to some steps in the process, is used to formalize descriptions of the process and its events to make them more visually accessible.

The 'pre-design development process' for the 'Design for Comfort' project (design activity process step № 1~4) was a prelude to my PhD research.

Table 12: The design activity process of the 'Design for Comfort' project

Step №	Verb	Noun/Object	Qualifier
1	Participated in	a session	at the Department Agriculture and Food Western Australia (DAFWA) to introduce the Shima Seiki WholeGarment® knitting system
2	Joined	the 'Design for Comfort' team	as a research student who would develop a PhD project on the role of 'machine interpreter' for Shima Seiki knitting system at DAFWA
3	Task informed		to design and make novel textiles for five Western Australian (WA) fashion/textile designers using WA merino wool and the Shima Seiki knitting system at DAFWA
4	Met with	one of the Design-for-Comfort project staff members	who knew the style and preference of each five designers to make samples for pre-selection before individual meetings
5	Received	an email	from another Design-for-Comfort project staff member asking how much fabric needed to be developed for each designer
6	Received	an email	recommending the focus to be on developing ONE simple, but exclusive fabric with each of the designers
7	Started	3 days of basic training	on the knitting system at DAFWA with a Design-for-Comfort project staff member who was previously trained at Shima Seiki in Japan
8	Continued	trial and error	on the knitting system, occasionally, with assistance of another staff member who was a senior research technician
9	Produced	fabrics	on the knitting machine much before the first formal training at Shima Seiki in Japan.
10	Received	design suggestions	from the project staff member who knew the style and preference of each five designer: irregularity with something hand-manipulated considered more valuable
11	Selected	samples	for each designer before initial meetings
12	Met with	each designer	individually - the liaison process
13	Received	different responses	from each designer as well as one similarity existed, which was the five designers did not mind imperfection of fabric at all. Even they mentioned defects were exciting
14	Asked	to keep two diaries	one for what is going on and the other for design development
15	Sent	a concerned email	regarding two matters
16	Received	a comforting email	
17	Produced	fabric	with no defect for the first time

18	Tried to source	yarn color swatch book	from overseas
19	Integrated	a new type of yarn	made from WA fiber to the project
20	Decided	fabric development order	from the difficult to the easy
21	Sent out	fabric samples	to each designer for confirmation
22	Began	production	finally
23	Sent out	the produced fabric	to each designer by courier service
24	Attended	the first formal residential training	at Shima Seiki in Japan
25	Received	extra fabric production request	from Designer E due to unsuccessful design outcome by over-felting
26	Had Designer E pick up extra fabric		
27	Observed	work of five designers	in the knitted fabric featured on Merino Innovation Day at Egerton in July 12, 2006

Project 2: 'Wagin Woolorama Ambassador 2007'

Reflection on the project

In January 31, 2007, the wool scientist asked me to design the WholeGarment® outfits for the Woolorama Ambassador of the year. She explained that on the 9th and 10th of March, the 34th Wagin Woolarama Trade Fair would be held in Wagin, 3 hours south of Perth. This large event attracts thousands of wool producers across the state and the Woolorama Ambassador walks around the fair speaking to visitors and exhibitors. Each year the Ambassador purchases wool garments to wear at the event. The wool scientist thought it might be a good opportunity for me to get involved in. The timing was right. I had just come back from my second official training at Shima Seiki.

The Woolorama Ambassador of the year 2007 visited me on February 12, 2007. She was medium height, full-figured and charming and specific about her outfits. She liked tight fitting clothes and she was modest. Her request was not difficult to fulfill. I had designed customized knitwear for women for a long time before I came to Australia. I knew exactly what she wanted.

During preparation for the design, there were technical problems in relation to take-downs, loop lengths, and yarn counts for the machine. These problems had not emerged in the 'Design for Comfort' project, because these were flat knitted fabrics. Also, I was fortunate that the designers appreciated my mistakes and thought mistakes made the fabric look more natural. This time the need was to create something commercially viable. After struggling, I asked for help from my tutor in Japan. This raised a cultural issue. I was supposed to consult the local Shima Seiki agent first. I believe it is the way how Japanese people operate their businesses. They pay respect to people in 'bridging positions'.

The technical barriers thrown up by the machine were bigger than I thought they would be after the 'Design for Comfort' project. Even though I had already had two formal training courses, which provided me with more credibility and more flexibility in my work, it was clear I needed more training in the near future.

On the first day of our meeting, the Ambassador tried on some trial prototype garments that had been created using the embedded body measurement chart of the Shima Seiki WholeGarment® knitting system. The Ambassador was helpful. After a few trials, she picked her favorite styles and colors. She preferred the V-necklines for both the ensemble and dress. These required two stitch patterns: a combination of missed and front stitches and 2x2 ribs. She also wanted two skirt lengths, one just above the knees and the other below the knees. I did not need to take her measurement. By watching her trying on the trial prototypes, I could discern the required body measurements. She was young and did not mind displaying her body. I made the knitwear following the machine's standardized body measurement chart while incorporating her preferences. The garments as required would cling to her shape the way she wanted.

In conventional fashion design, after deciding the style, flat pattern making or draping is the usual next step in producing *1st sample* in woven fabric. Using the Shima Seiki WholeGarment® knitting system I, instead, created several mock-up prototypes, based on the trial prototypes, to create *1st sample*. Therefore, the mock-up prototypes are derivatives of the trial prototypes.

The trial prototypes are produced following the knitting system's standardized body measurement chart to check this embedded body measurement chart in the knitting system. These trial prototypes can be knitted with inexpensive yarn or leftovers of the 'real' yarn. They are created for the purpose of making customized knitwear such as in the Ambassador's case. Figure 111 shows the Ambassador in the two different trial prototypes (two knitted dresses: dress 5 and dress 9). She was wearing them over her regular clothes.

Figure 111: Prototype modeling. Source: Courtesy of Ms Crystal McIvor

The mock-up prototypes are produced to check size specifications and design details and they are knitted with an inexpensive yarn such as acrylic that knits well. If every criterion meets the requirements, *1st sample* is then knitted with the 'real' yarn.

The standard way to create a one-piece sleeveless dress on the Shima Seiki knitting system is to combine a sleeveless top with a skirt. Table 13 displays the body measurement chart for both the mock-up prototype and actual garments. Knowing the garment construction of women's wear, this is a rather peculiar way of creating a dress. In flat pattern making, it can be done by elongating the top's hemline.

The same mock-up prototype was used to create the ensemble top and the top part of the dress. A straight skirt and a flared skirt were prototyped for the ensemble bottom and the bottom part of the dress, respectively. Small adjustments were made to the first mock-up prototype garment to better produce outfits. The main adjustments were to body length, hem width, hem rib length, waist width, and skirt length (Table 13). These are some of the basic measurements that control the form of the outer shape of the garment. There was no need for great changes. This sped up the garment development process. Note that even activating or inactivating the default value can make a difference in garment shape and fit, for example, hem rib length (6cm to 0cm) and skirt waist back drop (0cm to 1 cm).

Table 13: The body measurement of the prototype garments and actual outfits

	Measurement part	The first mock-up prototype (cm)	Actual outfit (cm)
ENSEMBLE (top): sleeveless	Body length	50	62
	Chest width	52	52
	Shoulder width	37	37
	Front bust width	37	37
	Back bust width	37	37
	Back neck width	26	26
	Front neck depth	18	18
	Back neck depth	3	3
	SP_neck depth		
	Straight arm hole	20.5	20.5
	Bind-off width (front body)	1.5	1.5
	Bind-off width (back body)	1.5	1.5
	Curve part/A.H. depth (F) ratio	0.5	0.5
	Curve part/A.H. depth (B) ratio	0.5	0.5
	Hem width	52	53.5
	Hem rib length	6	0
	Armhole rib length		
	Waist width	49	49
	Waist position from top	33	33
	Difference of body length		
ENSEMBLE (bottom): Straight skirt	Hem width	63	63
	Hem rib length	0	0
	Waist width (skirt / pants)	36	36
	Ease for waist width	4	4
	Skirt length	73	73
	Hip width	55	55
	Hip height	18	18
	Dart position from center	8	8
	Skirt waist back drop	1	1
TOP: Sleeveless	Body length	50	33
	Chest width	52	52
	Shoulder width	37	37
	Front bust width	37	37
	Back bust width	37	37
	Back neck width	26	26
	Front neck depth	18	18
	Back neck depth	3	3
	SP_neck depth		

	Straight arm hole	20.5	20.5
	Bind-off width (front body)	1.5	1.5
	Bind-off width (back body)	1.5	1.5
	Curve part/A.H. depth (F) ratio	0.5	0.5
	Curve part/A.H. depth (B) ratio	0.5	0.5
	Hem width	52	52
	Hem rib length	6 (default value)	0
	Armhole rib width		
	Waist width	49	52
	Waist position from top	33	33
	Difference of body length		
BOTTOM: Flared skirt	Hem rib length	1	1
	Waist width (skirt / pants)	49	52
	Ease for waist width	3	3
	Skirt length	46	71
	Skirt hem width (F+B)	130	130
	Skirt waist back drop	0	1 (default value)
	Skirt straight length	0.5	0.5

Figure 112 shows Crystal in the completed outfits. She sent me these photos along with a nice complimentary email.

Figure 112: Crystal in her rib dress (left) and in textured ensemble (right). Source: Courtesy of Ms Crystal McIvor

In the process of outfit development for the Ambassador, I contacted one of my tutors at Shima Seiki in Japan. Our email communication started on February 2 by his asking how I was doing on the knitting machine. It ended with my thank-you messages to him and my wish to see him again for my third formal training program on May 8.

After struggling two days on the knitting machine by myself, I had to send him an urgent-attention-required email. I begun to encounter a technical problem and Crystal was expected to come in for a garment trial in a couple of days. Nothing was coming out right from the machine. The loop size of the skirt front was totally different from that of the skirt back. The fabric quality of the back was much looser and coarser than the front (Figure 113). I could easily deal with it, if this situation happened now. I was appreciative of the tutor's responses. With his assistance, I was able to produce the ensemble in time.

The top also caused me the same problem as the skirt. I decided, therefore, I needed to do something to build up my technical skills further and planned the 3rd formal training at Shima Seiki.

Figure 113: The front and back of skirt in uneven quality

The outfit development timeline for the 'Wagin Woolorama Ambassador 2007' is shown in Figure 114.

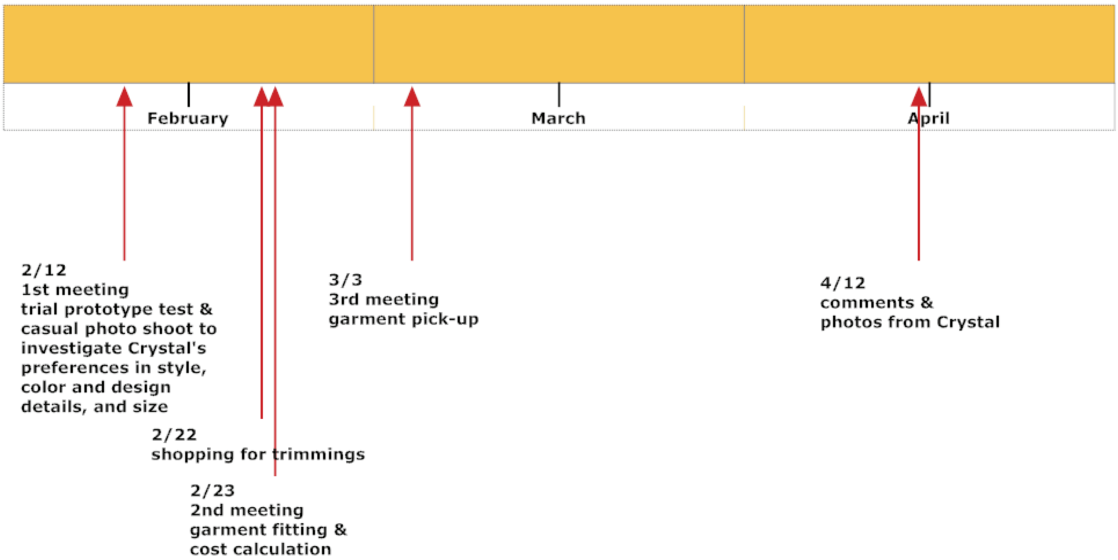


Figure 114: Time-line of Crystal's outfits development

Applied process mapping of the project

The following Table 14 profiles the project process initially derived from the investigation of emails and the printouts of the emails. The same applied process mapping technique was applied as explained Table 12.

Table 14: The design activity process of 'Wagin Woolorama Ambassador 2007'

Step №	Verb	Noun/Object	Qualifier
1	Received	an email	from the Design-for-Comfort project staff asking whether I would be interested in designing the WholeGarment® outfits for the Woolorama Ambassador of the year 2007
2	Met with	the Woolorama Ambassador of the year 2007	The Ambassador's trying on a few trial prototype garments[6] for me to find out her preference in style, color, design details, and size. Casual photo shoot done for size reference
3	Did not take	her body measurement	because of her preference for tight fitting garment
4	Encountered	technical problems	while preparing prototypes of *1st sample*
5	Struggled	for a couple of days	on the knitting machine to resolve the technical problems
6	Asked	a favor of	a tutor in Japan
7	Received	a dear and clear response	from the tutor in Microsoft Word files explaining all things that needed to be considered
8	Developed	several mock-up prototypes	based on the trial prototypes to develop *1st sample* with simple adjustments
9	Made	adjustments	to the embedded garment part measurement chart in SDS-ONE® *KnitPaint*: body length, hem width, hem rib length, waist width, and skirt length, respectively
10	Completed		to test the fit of garment
11	Went	shopping	for trimmings
12	Received	another response	from the tutor regarding the technical problems
13	Met with	the Woolorama Ambassador	a second time for garment fitting. Cost calculation of her outfits with the project staff
14	Completed	the three outfits	
15	Resolved	the technical problems	for this case, but felt a strong urge for next training
16	Met with	the Woolorama Ambassador	a third time for garment pickup
17	Received	a complimentary email	from the Woolorama Ambassador with her photos in the outfits
18	Planned	another formal training	

[6] The trial prototypes are produced on regular bases to check the embedded body measurements in the knitting system. They can be done with inexpensive yarn or left-over of the 'real' yarn. They are created for the purpose of making customized knitwear.

Project 3: Cone-shaped artifact

Reflection on the project

After the ‘Wagin Woolorama Ambassador 2007’ project, the wool scientist stopped by at the knitting studio and handed me a drawing (Figure 115).

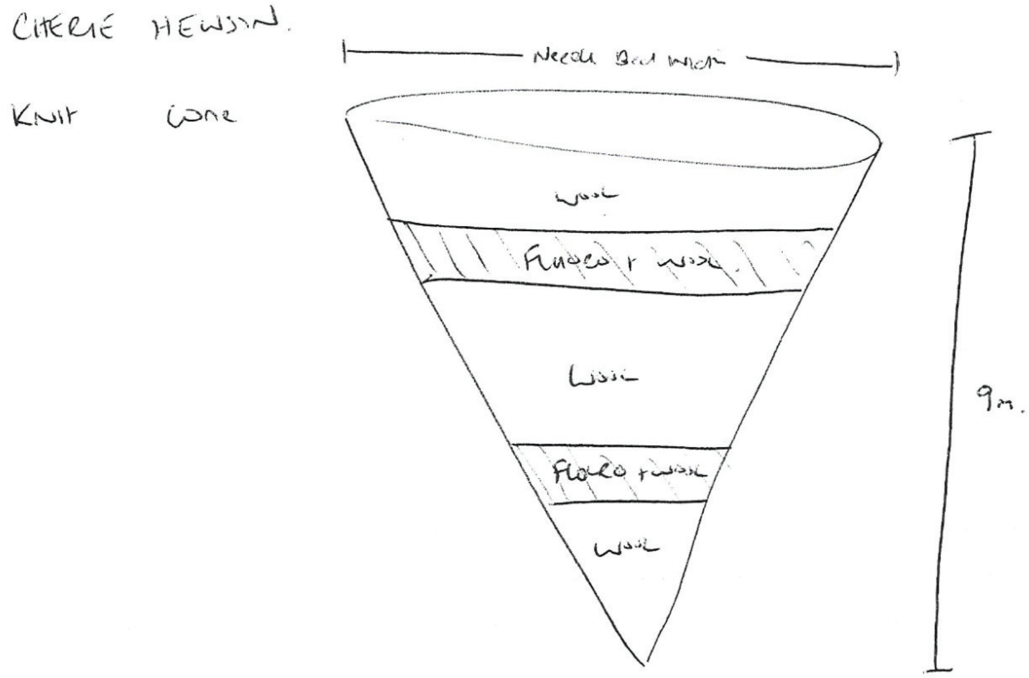


Figure 115: Original drawing of a cone-shaped artifact

She asked me whether or not it would be possible to make a 9 meter-long cone-shaped knitted artifact similar to lampshade. She explained the artifact would be displayed at a public exhibition at Burswood casino. I thought she meant 90 centimeters, not 9 meters! I recalled seeing images of prototype knitted light-cones in cotton that were formed seamlessly on the knitting machine made (Black, 2002, p. 171). I did not see the problem of a lamp shade in wool since the heat resistance temperature of both fiber were similar (cotton: 150C °and wool: 132 C °).

As I was preparing to program the design on the CAD system, I realized I was supposed to work on a 9 meter-long lamp shade, not a 90 centimeter-long one. I emailed the tutor in Japan briefly explaining what I needed to do and asking if he could suggest which pre-registered garment shape to use. He recommended using a shape that we did not have time to go over in training and its knit data was sent to me.

The missed out shape in the second formal training was a tube in an envelope shape (Figure 116).

Figure 116: An envelope shaped tube

What I needed to make was, however, a tube in a wedge shape (Figure 117), and a very large one.

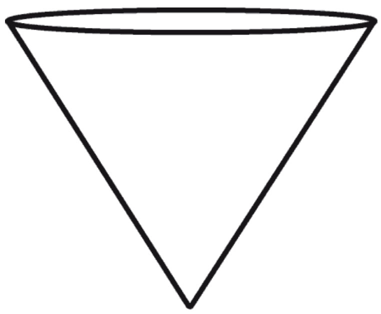


Figure 117: A wedge shaped tube

I tried to modify the bottom shape of the envelope to look like a tube. Theoretically, there should not have been any problem. The SDS-ONE® program, however, produced error messages.

I had to approach the problem all over again from the beginning trialing the pre-registered garment shapes in the CAD system. I picked one of the simplest shapes that appeared to be easily modifiable, the tight skirt shape. My plan was to change the tight skirt shape into the straight tube and then, transfer that tubular shape into the wedge shape, but with a small hole at the bottom (Figure 118).

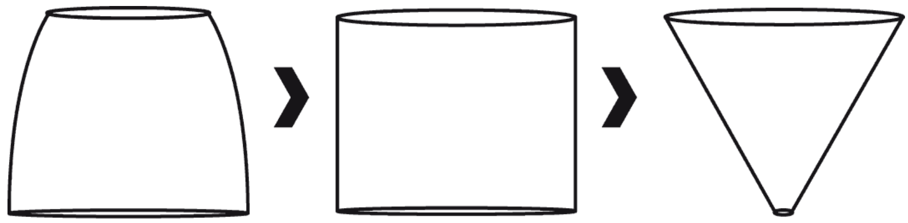


Figure 118: The sequence of making a funnel shape

It worked. To program a funnel-shaped tube in a child's headwear size, I increased the size, but the process failed as the size increased. I needed to come up with another approach. At that time, I was into using simple Mathematics, Combinatorics that could be applied to knitwear design development. I remembered a section of a fun math book (Burns, 1982) about the Fibonacci numbers. I thought it might be worth trying. I was so surprised at how well the Fibonacci numbers worked out. Without much of a struggle, I could program a jumbo lamp shade close to the original measurement specifications (8.3 meter in length and 1.4 meter in width). I was so proud of myself and I emailed to my supervisor who commented that the Fibonacci numbers tend to work well with computer programs.

Several other issues emerged, however:

- There were problems with yarn. The cone-shaped artifact was to be produced with expensive reflective yarn, but sampling the artifact would need prototyping with expensive wool yarn.
- Too much yarn consumption to make the requested sample
- Not being able to use 1 end of 1/15 or 2 ends of 2/30's wool yarns in stock
- Medium quality of knitted fabric with 2 ends of 2/30's, but not the best quality, probably with three or four ends of 2/60's would produce a better quality of fabric
- No ironing or finishing facilities to accommodate such a gigantic knitted artifact at DAFWA (it might need to be taken to a professional dry-cleaner).
- Plan to make an 89 centimeter-long, 144 centimeter-wide sample, which was 1/9th of the original length to give the commissioner lady the idea of how wide the shade would be.
- 8.3 meter in length 1.4 meter in width was the closest I could get without a knit data error. Any length longer than this length would be impossible to process at this moment.
- In need of some serious needle changes before working on the sample.

- Are there more 2/30’s white yarn? Seemed like there were not enough yarn for sampling. Needed DAFWA’s confirmation to go ahead while mentioning the sample could be done in two hours, if nothing went wrong. Also, I would still need to try the fluorescent yarn as stripes on the knitting machine (see Figure 87).

I emailed these concerns to the wool scientist. She emailed me back saying she would have to discuss the issues with the person commissioning this project, and get back to me. She suggested that it would be all right to show the samples I had done and asked me to go ahead with the 89 centimeter-long, 144 centimeter-wide sample but not to use any of the white yarn, which was the 2/60’s and twice as expensive as the 2/30’s. She was quite specific about the usage of yarn and things for me to do this time. She commented that the 2/60’s white was too precious to be used on this project. Additionally, she asked me to pick another color and only use the 2/30's for this sample.

She also requested I add up the total amount of yarn used for this project, so she could work out the cost of yarn used. She emphasized this would be important for us to know for future projects like this.

The wool scientist and I met the artist in the knitting studio at DAFWA on March 23. I handed over one of miniature prototypes. The meeting with the artist went well and she promised me to give the contact detail for Lurex yarn.

On April 17, I received an email from the Lurex agent in Australia. The agent informed me of the un-availability of wool yarn in stock at his company and he commented that Lurex might supply a small sample cone. I received two of tiny Lurex sample cones and they knitted easily. I contacted the person commissioning the project and the project stalled at that point – perhaps because of the yarn cost (USD 303.00/kg).

Applied process mapping of the project

The following Table

15 profiles the project process initially derived from the investigation of emails and the printouts of the emails. The same applied process mapping technique was applied as explained Table 22.

Table 15: The design activity process of Cone-shaped artifact

Step №	Verb	Noun/Object	Qualifier
1	Received	a request	from the Design-for-Comfort project staff member asking possibility of creating a 9 meter-long cone-shaped knitted artifact (looking like a jumbo lamp shade) for display at Burswood Casino.
2	Sent	an email	to the tutor asking which pre-registered garment shape to use to develop the design.
3	Received	a reply email	from the tutor saying that to use a previously sent knit data for own practice
4	Had	a successful trial	of the previously sent data on the knitting machine
5	Encountered	programming errors	of the 9 meter-long cone-shaped knitted artifact due to its enormous size
6	Applied	Fibonacci numbers	to extreme measurement out of curiosity: some worked while some did not
7	Continued	trial of applying Fibonacci numbers	to investigate programmable extreme measurement as close as possible to the original measurement
8	Identified	the closest possible measurement	without 'Auto Process' error found: 8.3meter in length and 1.4meter in width
9	Completed	miniature prototypes	of the original jumbo lamp shade
10	Sent	an email	to the Design-for-Comfort project staff regarding four issues
11	Planned	to make an 89cm-long and 144cm-wide prototype	in wool, 1/9th of the original measurement
12	Needed	fluorescent yarn	for trial on the knitting machine
13	Sent	an email	to the lady who commissioned the huge lamp shade for a visit
14	Met with	the commissioner lady	
15	Handed over	one of miniature prototypes	to the lady
16	Sent	an email	to the lady asking for contact details of fluorescent yarn
17	Contacted	customer services	of the fluorescent yarn company
18	Identified	Australian agent	of the fluorescent company
19	Received	an email	notifying the price of fluorescent yarn: USD303.00/kg
20	Received	irreducible amount	of yarn to test and color swatch books of fluorescent yarn
21	Tried	miniature prototypes	with fluorescent yarn
22	Completed	miniature prototypes	made of fluorescent yarn
23	Sent	an email	to the lady informing completion of miniatures with fluorescent yarn and the price of fluorescent yarn
24	Received	no feedback	afterwards

Project 4: Tube sessions 2007 at Curtin University of Technology

Reflection on the project

In May 11, 2007, I took up a sessional academic position in the Design Department at Curtin University to develop various forms of tube designs in different stitch patterns incorporated in the CAD library of the knitting system for use in teaching Fashion and Textile Design students. This post would start after the third formal training program in July at Shima Seiki and I would be more confident working on the knitting machine after the training course.

I had to teach thirty of the second year students majoring in Fashion and Textile Design with only one knitting system, and the knitting studio was too small to hold thirty students at a time. The lecturer divided the students into four groups and I repeated the same session four times each day. This was a drawback for students. They preferred a four-hour-per-week lesson instead of a one-hour-per-week lesson, which would have been possible if the knitting studio had been more spacious.

Before the sessions, I had a half day demonstration with Bentley TAFE students who were in the same area of study as the Curtin students. They wanted to see the machine in operation before their final project presentation. I spent much more time with them than they had asked for, because there were many questions from accompanying tutors as well as students. They were busy taking photos and going through samples. On the contrary, one third or less of the Curtin students expressed no interest and were not mentally engaging in the class. The students seemed overwhelmed by the high technology knitting system. There was very little time allocated for individual students. I wonder if I had spent more time with students individually, what difference it would have made. Would the experience have been more positive or more negative? How many students really appreciated the fact that they had a chance to be exposed to the latest knitting technology?

The wool scientist had informed me that the DAFWA manager at that time had approved Curtin students on site at DAFWA on September 6 and mentioned she would clear any difficulties regarding Occupational Health and Safety.

In preparation for the sessions, emails were exchanged about setting up guidelines for Curtin students at the knitting studio. The lecturer asked me to get the easiest yarn to work with on the knitting machine. Initially, I tried to obtain yarn from Cheil Industry in Korea, which had supported my PhD. There were difficulties with export that required finding an Australian or European yarn supplier. Eventually, the yarn that was obtained was

Cashwool® from Zegna Baruffa (ZB) specially designed for knitting on the Shima Seiki knitting machine. After several emails, 13 kilograms of white 2/30 Cashwool® were finally ordered on September 17. Due to payment issues, there was a delay, but the yarn arrived at DAFWA just in time, on October 3.

Before the beginning of the tutorial sessions, I suggested to the lecturer to hold an introductory class at Curtin. I was concerned about not having enough time for design development. Copies of the guidelines and twelve tube diagrams were supplied to the students along with several knitted tube samples made at a quarter of a size 8 female body, and a booklet of the pattern library embedded in the programming workstation of the Shima Seiki knitting system. The booklet demonstrated how many design choices students could have for their tube projects. There are more than 800 different stitch patterns possible. Endless numbers of designs can be created if Combinatorics is applied (Yang 2007, p. 19), and added into the pattern library. The following table 16 describes how each session with the students was organized and how the sessions progressed.

Table 16: Class management of the tube sessions_2007

September 11, 2007: Introductory class	Distributing two hand-outs to students: Guidelines for Curtin students at Knitting Studio Department of Agriculture and Food WA (DAFWA) Tube drawings (12 tube designs, 66 selections) Viewing of tube samples (1/4 of the size 8 female body) Asking students to work in pairs. Also, requesting them to have a look at the CAD generated stitch pattern book to make selections for their project. Stating an email would be sent to students as a reminder before class.	
September 18, 2007: First session	Mini lectures on: Introduction to WholeGarment® knitting technology Types of knitwear production Some practical issues in WholeGarment® knitting technology regarding: Machine, Yarn, and Skills and training. Yarn allocation: 350g of yarn for each pair Request for students to bring a set of blunt sewing needles and a pair of mini-scissors Request for an email including the following information by the following day (Wednesday 19th): Your group Your name and that of your partner Your email address Your mobile-phone number (in case of emergency) Your selection of stitch patterns	e-mails to students: September 21, 2007 Dear All: I have not received emails from 5 students; it's your responsibility. For next class, please bring a set of blunt sewing needles and scissor. Also, be ready for a 5 minutes presentation on your tube project. It will be recorded. See you. Kind Regards, Sooyung Yang --- Dear All: All your selections are knit-able. Good choices! For those who have not sent me their emails, make sure you are well prepared for the 5 minute presentation. Have a good weekend! Kind Regards, Sooyung Yang

October 2, 2007: Second session	5 minute presentation by each pair on tube project Confirmation of stitch patterns (each student was given a stitch pattern sample of his/her choice) Documentation and submission of a draft of production sheet	e-mails to students: October 2, 2007 Dear All: Here is the web site address: http://bendigowoolenmills.com.au Phone: 03-5442-4600 Please ask for the free shade card, if interested. Kind Regards, Sooyung Yang --- e-mail to students: October 6. 2007 Dear All: Please bring extra copies of production sheets, images, photos, and drawing supplies for technical drawings. You need to bring your own stationery, if required. Make sure you are well prepared, so you can submit them in class. This will be the last time to talk about your project. Please be aware no changes are allowed on previous drawings you gave me, but you need to elaborate on them as specifically as possible for production. Thank you. Have a good weekend! Kind Regards, Sooyung Yang
October 9, 2007: Third session	Documentation and submission of the production sheet	e-mail to students: October 13. 2007 Dear All: Please bring blunt needles and a pair of mini scissors for next class. You are going to work on finishing work. You will practise proper finishing work on your swatch and prototype garment. Those who kept sample swatches and prototypes don't forget to bring them in. Have a good weekend! Kind Regards, Sooyung Yang

October 16, 2007: Fourth session	Distribution of prototype tubes Working on proper knitwear finishing work (each pair was given her choice of prototype tubes and stitch patterns to confirm his/her designs and to learn finishing work) Confirmation of the production sheet	e-mail to students: October 28. 2007 Dear All: All your samples are ready. Please bring all the equipment for proper knitwear finishing work. Also, don't forget to bring the mini-ironing board and wear shoes that cover your feet completely. See you at Curtin for the last class. Kind Regards, Sooyung Yang
October 23, 2007	No class!	
October 30, 2007: Fifth session	Distribution of tube garments to each pair Instructions on proper ironing	
November 13, 2007	Assessment	
November 15, 2007	Photo shoot	

The tube class went really well and the lecturer organized a photo shoot to document some of the best tube garments. She also invited the senior DAFWA researcher and the wool scientist on the assessment day on November 13. The photo shoot was on November 15 with two models. The lecturer's application for funds was successful and a professional photographer was hired and Curtin's photography studio was rented. The photo shoot was a success. It made me forget how embarrassed I was on the assessment day. The successful outcome of the tube class led to another event in 2008.

Applied process mapping of the project

The following Table 17 profiles the project process initially derived from the investigation of emails and the printouts of the emails. The same applied process mapping technique was applied as explained Table 12.

Table 17: The design activity process of Tube sessions 2007 at Curtin

Step №	Verb	Noun/Object	Qualifier
1	Being offered	a sessional academic position	at Design Department of Curtin University
2	Received	an approval	regarding Curtin students on site at DAFWA
3	Prepared	several base tubular shapes	that were designed, programmed, and knitted
4	Set up	guidelines	for Curtin students at the knitting studio
5	Tried to source	yarn	from overseas for students' work initially: unsuccessful
6	Tried to source	yarn	from overseas for students' work for second time: successful and able to source the best suitable yarn for the knitting machine at DAFWA with advice of the tutor
7	Held	an introductory class	prior to main sessions
8	Created	more tubular shapes	to guide students' work
9	Placed	the main order	for yarn
10	Held	first session	to distribute two hand-outs to students, to show the students tube samples (1/4 of the size 8 female body), to request the students to work in pairs, to request the students to have a look at the CAD generated stitch patterns book to make selections for their work, and to inform the students an email would be sent to students as a reminder before class
11	Held	second session	to have each pair have five minute presentation on their tube work, to confirm stitch patterns of individual students who were given a stitch pattern swatch of their choice, and to have each pair document and submit a draft of production sheet
12	Received	the main yarn	arrived at DAFWA from Italy
13	Held	third session	to have each pair document and submit the production sheet
14	Held	fourth session	to distribute prototype tubes, to demonstrate how to do the proper knitwear finishing work (each pair was given their choice of prototype tubes and stitch pattern swatches to confirm their designs and to learn finishing work), and to confirm the production sheet
15	Held	fifth session	to distributed tube garments to each pair and to demonstrate proper ironing
16	Participated in	assessment	
17	Participated in	professional photo shoot	

Project 5: Knitwear design using Merino Soul's yarn

Reflection on the project

In November 11, 2007 Bianca Gervasio, a designer from Italy visited me as part her collaborative collocation with the Wool Desk at DAFWA. We worked together closely for two weeks. It was a pleasure to work with her. At the same time, I had to spend an enormous amount of time to convince her some of her designs were not feasible on the knitting machine due to limitations of the machine (and my lack of technical expertise). I explained the situation with the help of a staff member from DAFWA, whose mother tongue is Italian.

Bianca asked for exaggerated fabric manipulation, which could be expedited on a hand-framed knitting machine but is time-consuming on the Shima Seiki WholeGarment® knitting machine. The embedded pre-registered garment shapes can be modified to a certain degree. The strict time limit restricted the number of her designs that were produced on the knitting machine. Some of her more extreme designs could have been created by developing ‘packages’. However, time was too short to explore these possibilities without more preparations. During the period of her stay, we reached a compromise.

Bianca was explicit about her creations which were classic, minimal and with a modern flair. She was interested in bubbles and folds for her collection. She preferred semi-fitted styles and had a distinctive color palette that was dark, but well coordinated.

After the design negotiation with her, there were more confidence and there was reasonably good support from the local Shima Seiki technician in Melbourne. This technical support is a very useful even though the nature of the commercial arrangements means that industry customers come first in support. Increasingly, after two and half years now, the support person understands the unusual requests required for my PhD which differ from the more conventional requests for technical support for retail mass production.

Bianca presented this work as part of a new collection in Rome on July 8 2008 and it can be seen where her work is being displayed at AltaRomAltaRoma 2008 (Figure 119). I was informed by DAFWA staff of Bianca’s satisfaction with the event’s response.

Figure 119: Knitted strip ornamentation on catwalk. Source: (AltaRoma, 2008)

Applied process mapping of the project

The following Table 18 profiles the project process initially derived from the investigation of emails and the printouts of the emails. The same applied process mapping technique was applied as explained Table 12.

Table 18: The design activity process of Knitwear design using Merino Soul's yarn

Step №	Verb	Noun/Object	Qualifier
1	Received	an email	from the project manager announcing the project under the way
2	Received	an email	from the project manager informing an Italian designer's near arrival for her collaborative collocation with Wool Desk at DAFWA
3	Received	the Merino Soul's yarn	from Italy
4	Met with	the Italian designer	accompanied by the project manager to discuss the fabric development on the knitting system at DAFWA and to view her look-book and a few signatures initially
5	Met with	the Italian designer	to have a chance to explain briefly how the knitting system was operated for second time
6	Received	an email	from the project manager asking for media release
7	Met with	the Italian designer	for third time
8	Met with	the Italian designer	for fourth time
9	Met with	the Italian designer	for fifth time
10	Met with	the Italian designer	for sixth time
11	Met with	the Italian designer	for seventh time to hand over some of fabric and WholeGarment® to her before her departure
12	Engaged in	further studio production work	to complete the Italian designer's request
13	Informed	the Italian designer	the shortage of yarn to complete her design request and in need of her confirmation using similar yarn
14	Received	the designer's confirmation	via the project manager
15	Completed	production	
16	Requested	all produced fabric	to be sent to the Italian designer
17	Received	an invitation	to AltaRoma announcing the Italian designer's presentation of her new collection in Rome at AltaRoma fashion week, on the 8th of July 2008
18	Received	an email	from the project manager reporting the Italian designer's satisfaction with the event's response
19	Shared	a congratulation email	from the Director General of DAFWA on the project's successful outcome

Project 6: Professional Practicum 390 at Curtin

Reflection on the project

After the Tube sessions 2007 at Curtin, I received an email from one of Curtin students who took the tube sessions, asking for work experience. Over the next two days there were phone calls from two more Curtin students asking for work experience. I was glad to have an opportunity to work with students who are willing to work hard and be creative in their own ways. One was good at hand-framed machine knitting and two were good at crocheting.

Prior to an initial meeting with the students, I met with my associate supervisor at DAFWA to discuss this work experience and ask him if he had anything special in his mind for us to work on. He said he would be happy if we could make some samples that would be sent to a renowned Italian spinner, 'Chiavazza'.

I made eighteen miniature WholeGarment® dresses for the students to work on for their 40-hour work experience.

The size of each of these WholeGarment® dresses was a quarter size of the size 8 female body. At the first meeting in February 29, 2008 in the knitting studio at DAFWA, it was explained to the students that work from their work experience would be kept in the knitting studio, but they would receive full acknowledgement whenever their work was made public.

The structure of the work experience was as follows:

- What to do for work experience? To work on 'Chiavazza' project;
- What needs to be done? To develop miniature samples to be sent to a renowned Italian yarn spinner 'Chiavazza';
- How to work it out? Six miniature dresses in 100% WA Merino wool given to each student. Need to be embellished in their own ways partly using felt-able wool;
- Work at home at their own pace, meet in the knitting studio once a week, and bring all their work along with them; and
- How to be marked? Summit a professional work diary of 40 hours at the end of last meeting.

Each student was given six WholeGarment® miniature dresses at the end of the meeting.

The knitting studio where I work is located in the storage area of DAFWA, due to the size of the knitting machine. It cannot easily fit into an office area and is noisy when it is operating; although much quieter than the computerized Italian knitting machine that I used to work with.

At the next meeting, one of the students brought a miniature dummy with her. And the other two students later purchased miniature dummies. Felt-able wool yarn was distributed to each student for garment decoration and I asked them to incorporate the felt-able wool yarn in their work in one way or another.

At the next meeting, only one student used the felt-able wool the way I expected. One student had problems with organization and workload. This is expected. Studying Fashion and Textile Design major demands substantial self-discipline and mental as well as physical engagement to complete the required subjects. Some students have personal circumstances that make this more difficult. Regardless, all the students work emerged tidy and professional.

Marks were given to the students on time and completed miniature garments were displayed at Royal Perth Show along with the tube garments produced in 2007. There was a professional photo shoot at the end of year for the miniature garments made for 'Chiavazza' project along with the tube garments of 2008 (Figure 120). Some work samples looked so good that I asked the Design-for-Comfort team to retain them.

Figure 120: Tubes with post-embellishment. Source: (DAFWA, 2008)

Applied process mapping of the project

The following Table 19 profiles the project process initially derived from the investigation of emails and the printouts of the emails. The same applied process mapping technique was applied as explained Table 12.

Table 19: The design activity process of Professional Practicum 390 at Curtin

Step №	Verb	Noun/Object	Qualifier
1	Received	an email	from a second year Curtin student who worked on the tube garment asking for work experience
2	Received	a phone call	from two more Curtin students asking for work experience
3	Prepared	18 of miniature WholeGarment® dresses	for the students to work on
4	Met with	three Curtin students	to discuss the work experience structure initially
5	Confirmed	all of them agreed	with the work experience structure
6	Received	a 'thank you' letter	from Head of Department, Art at Curtin University of Technology for agreeing to host the students for their work experience along with assessment details
7	Noticed	one of the students	inspiring two other students by presenting her work on baby dummies
8	Distributed	felt-able wool yarn	to the students for garment decoration
9	Gave	purchase information	on miniature mannequins given to two other students
10	Noticed	one of the students	, who had encountered a problem with her hand-framed knitting machine, later present more thorough work to make-up
11	Sensed	competition	going on among students
12	Gave	brief guidelines	on how to compose the first or intro page of work diary to the students
13	Received	a request	from the students: what kind of company would receive their work?
14	Held	mock presentation	of the students' work for their final submission
15	Gave	feedback	on the students' work – requested to meet the standard making them look more tidy and professional
16	Conducted	final submission	of the students' work
17	Gave	marks	to the students
18	Had	miniature samples	ready for display at Royal Perth Show along with the tube garments produced in 2007
19	Participated in	professional photo shoot	at the end of year for the tube garment of 2008 along with the miniature samples
20	Asked	the team	to send only one of the miniature samples to 'Chiavazza'

Project 7: Dance performance at the Livestock Updates 2008

Reflection on the project

One of the three students involved in the previous internship project (Professional Practicum 390) commented that dancers would love to wear some of my samples. She is a dancer herself and had also been involved in modeling the wool garments made by the second year students' on the photo shoot. She commented that she would be very comfortable and feel beautiful wearing the garments while dancing. I reflected that most dance outfits neither transfer body heat nor absorb sweat. Moreover, they cling to the body. The conversation with her gave me some thoughts about wool performance wear.

At the end of April, the senior project coordinator and DAFWA senior researcher visited the studio. We discussed the tube garments made by the second year students being part of the graduation fashion show. The senior project coordinator mentioned that the second year students would need the third year students' approval, which could be complicated. At that point, I brought up the previous student's comment on wool dancewear. Our conversation moved onto having a dance performance with the second year students' work at the graduation fashion show. Later, because the Wooldesk's own dance performance event was scheduled for the Livestock Updates, the DAFWA senior researcher decided to focus on the conference as the best means to demonstrate the tube project work and wool research, in general.

There were some difficulties in obtaining the original tube garments and ironically, their negligence offered me easy access to most students' work and taught me that I need to collect their work immediately after assessment.

On May 9, the DAFWA senior researcher emailed me to develop promotional items that could be given to important visitors due within the next few weeks. When we met a couple of days later, he took me the team's office at Technology Park. I met team members and the DAFWA senior researcher brought up the topic of a dance performance. I told him I had in mind a powerful sexy dance performance with a group of ten sleek professional dancers. The team looked astonished. I was sure that would attract an audience and one of the staff prepared the flyer (Figure 121).

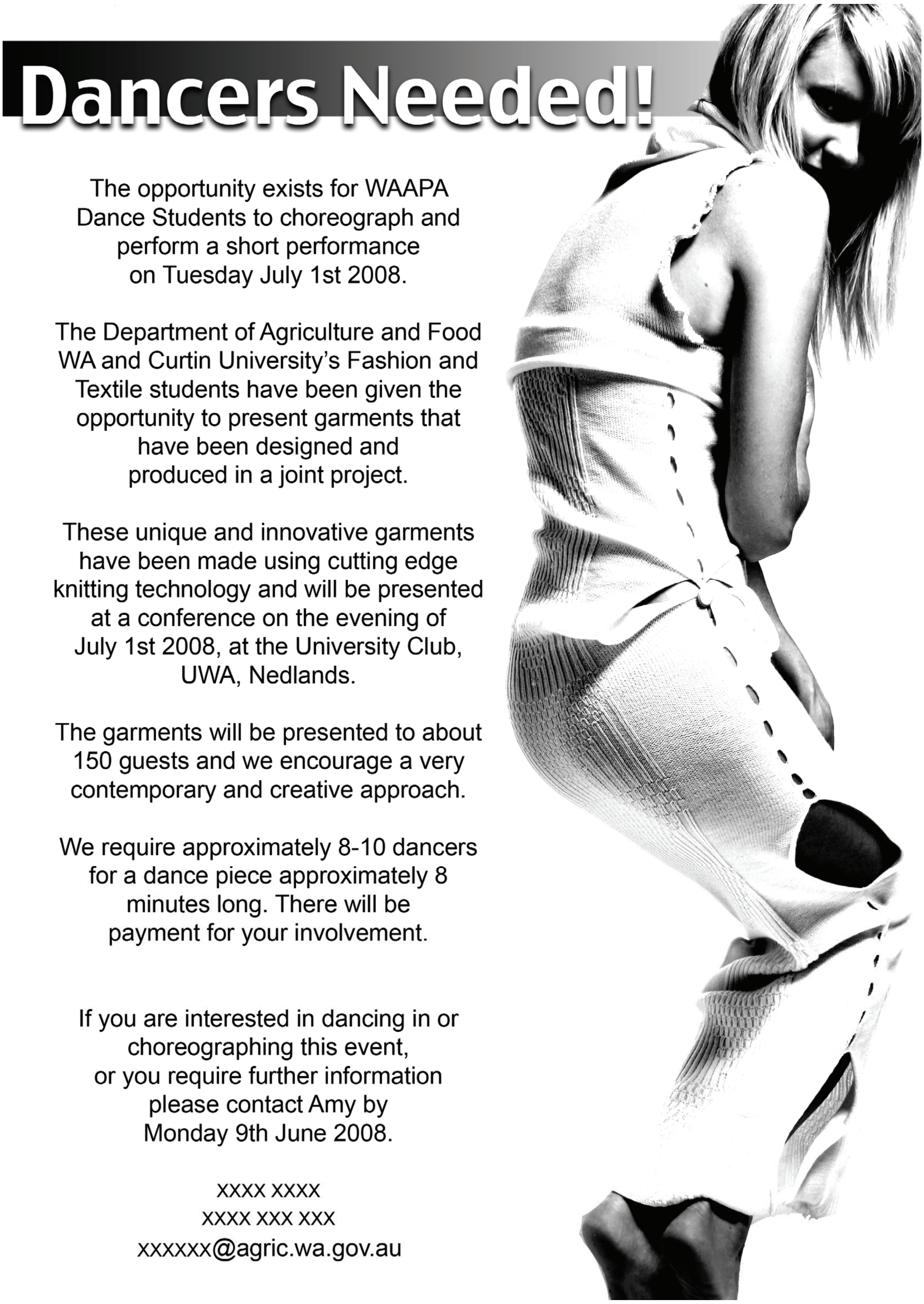


Figure 121: Call for 'Woolly Dancers'. Source: (DAFWA, 2008)

On the morning of Saturday June 14, at WAPPA at Edith Cowan University, a garment selection was arranged from the students' work for the dancers to choose from. We were also invited to a quick preview of the dance performance that would be featured at the Livestock Conference. The dance concept was changed to become more aesthetic rather than sexy in part to reflect the youth of the dancers.

Each dancer chose her own garment and tried it on. Then, they tried to move in them. I was sure the tube garments would work as performance wear but I did not expect one drawback. The bind-off, a kind of edging on the top of knitted garments or fabric that prevents loops being unraveled, was restricting the dancers' movements. A few dancers had to wear their tube garments upside down and put their arms and legs through bigger holes in the garments to free up their movement. As a result, four of the tube garments needed to be reproduced (Figure 122).

Figure 122: The dancers in their choices of tube garments

Because they had slight frames, the dancers needed more body coverage in brighter colors. It was suggested that each dancer should wear a pair of knitted wool stockings. I was not sure whether I could program them successfully because of the shape combination and proportions (remembering the difficulties with the 9 meter cone-shaped artifact). Immediately the meeting was over, I returned to the studio and started to program a couple of designs for stockings. As it turned out, it was not difficult and I could modify the pants template embedded in the CAD system. I ended up finishing the tube garments and stockings by myself. People disappear when it comes to garment finishing.

On the evening of July 1, we returned to The University Club of Western Australia where the Livestock Conference 2008 was held. The DAFWA senior researcher gave us a hand, but politely refused to view the dance performance. I still have no clue why he did not want to come in. I was impressed with the size of the waiting room that the sponsor offered, and the staff services. The team hired a professional make-up artist and photographer for the event. The dancers were there on time. Once made up, the dancers looked mature and professional in their tube outfits. They reminded me of 'Odette in Swan Lake'. What I had in mind was the image of 'Odile', the black swan. I must admit the 'Odette' concept was more suitable for this occasion since the dancers had soft body figures and their performance was presented in white attire (Figure 123).

Figure 123: The performing dancers in their white tube outfits. Source: (DAFWA, 2008)

When the dance performance was over, the dancers received well deserved applause from the Director General of DAFWA and the audience. While waiting for the dancers to finish their make-up, the choreographer asked whether the dance team could keep the wool stockings and DAFWA agreed to gift the stockings to the dancers.

Applied process mapping of the project

The following Table 20 profiles the project process initially derived from the investigation of emails and the printouts of the emails. The same applied process mapping technique was applied as explained Table 12.

Table 20: The design activity process of Dance Performance at the Livestock Updates 2008

Step №	Verb	Noun/Object	Qualifier
1	Identified	comments	from a student who happened to be a dancer on the last day of meeting for 'Chiavazza' project led some thoughts about wool performance wear
2	Met with	two of the Design-for-Comfort project staff member	at the Knitting studio. Brought up the student dancer's comments on wool dancewear
3	Had	the comments	later scheduled to hold the Wooldesk's own dance performance night at the Livestock Updates
4	Collected	the tube garments of 2007	from the second year students (now on their final year) for the dance performance night
5	Visited	the Design-for-Comfort team's office	at Technology Park, being formally introduced to new staff
6	Expressed	my own version of	the dance performance: a power sexy dance performance with a group of ten professional dancers in fully developed and somewhat masculine bodies
7	Heard	a flyer prepared	by one of the new project staff member, which was "Call for 'Wooly Dancers'"
8	Met with	the dancers	for them to choose their own the students' work initially (tube garments).
9	Identified	drawbacks	at rehearsal
10	Indicated	four of the tube garments	needed to be reproduced
11	Agreed with	the idea of	more body coverage by wearing stockings brought up due to the dancers' small build
12	Produced	wool stockings	on the knitting system in no time: felt happy about being successful with little input
13	Participated in	'Dance performance night'	
14	Had	the dancers	keep the stockings in exchange for filling out some questionnaires
15	Celebrated on	fantastic presentation	

Project 8: Tube sessions 2008 at Curtin University of Technology

Reflection on the project

In mid June 2008, the senior project coordinator initiated upcoming tube sessions for the next semester and wool yarn for students' work was accordingly put on order. This was a much smoother preparation for the upcoming sessions than previously.

Confusion over the yarn order occurred. Acrylic yarn was also ordered to prototype students' work before making the final product (*1st samples*). Prototyping garments in acrylic yarn saves expensive wool yarn, which is more than double the price of the acrylic. The order contained several types of yarn, including the Set-up Yarn and Draw Yarn for the knitting machine (Shima Seiki Mfg., n.d.-a), plus 100% cotton and nylon for testing purpose, were ordered as well as the acrylic yarn and the wool yarn for students' main work (1st sample). The complexity of the project and financial arrangements of this project between Curtin and DAFWA later caused substantial confusion for staff both at Curtin and at DAFWA, over which yarn needed to be invoiced where, and for how much.

The course schedule for the tube sessions in 2008 was similar to the tube sessions of 2007 (see Table 16). In contrast to 2007, information on contact details and stitch pattern preference were requested in the introductory session rather than on the first session to give the students more out-of-class time to think about their designs and more freedom of choice over selection of the stitch patterns. The 2007 experience told me students seemed to influence each other in the studio and unfortunately this resulted in them producing similar rather than creative work in the class environment.

The students were allowed to exchange or use other's selections, with approval, in order for them to work with the stitch patterns they were keen on, to support their creativity. A week interval was scheduled to be more time efficient between two sessions before distribution of the prototypes.

Table 21: Class management of the tube sessions_2008

September 03, 2008: Introductory session at Curtin 10:00AM~12:00PM	Distributing two hand-outs to students: Guidelines for Curtin students at Knitting Studio Department of Agriculture and Food WA (DAFWA) Tube drawings (12 tube designs, 66 selections) Viewing of tube samples (1/4 of the size 8 female body) Requesting students to work in pairs. Also, asking them to have a look at the CAD generated stitch pattern book to make selections for their project. Informing an email would be sent to students as a reminder before class. Request for an email including the following information by September 10[7] Your group Your name and that of your partner Your email address Your mobile-phone number (in case of emergency) Your selection of stitch pattern
September 17, 2008: First session at DAFWA Session schedule: Group1: 10:00AM~12:00PM Group2: 12:30PM~14:30PM	Confirmation of stitch patterns (each student was given a stitch pattern sample of his/her choice) --- being able to exchange or use other's selections with approval Mini lectures on: Introduction to WholeGarment® knitting technology Types of knitwear production Some practical issues in WholeGarment® knitting technology regarding: Machine, Yarn, and Skills and training Yarn allocation: 350g of yarn for each pair Request for students to bring a set of blunt sewing needles, a pair of mini-scissors and other related accessories
September 24, 2008: Second session at DAFWA Session schedule: Group1: 10:00AM~12:00PM Group2: 12:30PM~14:30PM	5 minute presentation by each pair on their tube project Documentation and submission of a draft of design specification sheet

[7] This information in the gray shaded area was requested on the 1st session in 2007, not on the introductory session.

October 1, 2008: Third session at DAFWA Session schedule: Group1: 10:00AM~12:00PM Group2: 12:30PM~14:30PM	Documentation and submission of the design specification sheet
October 8, 2008	No class![8]
October 15, 2008: Third Fourth at DAFWA Session schedule: Group1: 10:00AM~12:00PM Group2: 12:30PM~14:30PM	Distribution of prototype tubes Working on proper knitwear finishing work (each pair was given his/her choice of prototype tubes and stitch patterns to confirm her designs and to learn finishing work) Confirmation of the design specification sheet
October 22, 2008	No class!
October 29, 2008: Third Fifth session at Curtin Session schedule: Group1: 10:00AM~12:00PM Group2: 12:30PM~14:30PM	Distribution of tube garments to each pair Instructions on proper ironing
November 7, 2008	Assessment
December 10, 2008	Photo shoot

[8] It was newly scheduled for the tube sessions 2008.

Reviewing the experiences of the course, there were improvements in the application of more programming techniques in developing knitwear designs as well as more experimentation of innovative ways to create knitted garments. Table 22 compares the programming techniques of design details that were made in 2007 tube sessions and those in 2008 tube sessions show how the lessons of tube sessions 2008 were based on those of tube sessions 2007. The design details of 2007 such as borders, patterning in specific body parts, stitch pattern combinations, and regular holes along the top and bottom edges were repeated throughout the two tube sessions. On the other hand, there were new types of design details introduced, such as use of slits and garment development via unconventional garment shapes. This experimentation was intentionally geared to developing novel knitwear designs by integrating shapes and structures (stitch patterns).

Table 22: Comparison of the programming techniques used for knitwear design details between 2007 and 2008

Tube sessions 2007 at Curtin (28)		**Tube sessions 2008 at Curtin (49)**	
Border repeat, borders	3	1x1 stitch pattern, regular holes along the top edge	1
Patterned except specific part	1	2 slits in one panel	5
Stitch pattern combination	13	2x2 stitch pattern	1
Patterned (1 only sample present)	4	2x2 stitch pattern only in abdominal region	1
Patterned only in the center	1	3 slits in one pattern	1
Data from prototype	3	Area measurement of compressed pattern	1
regular holes along the top & bottom edges	3	Area measurement of compressed pattern, hexagon shape	3
		Area measurement of compressed pattern, originally barrel shape	2
		Border as pattern	1
		Border on top and bottom	1
		Stitch pattern combination	2
		Stitch pattern combination, area measurement of compressed pattern, hexagon shape	1
		Female bottle shape	1
		Inserted cutting lines for dye swatches	1
		Narrowed range-hood shape	1
		Octagon shape	2
		Ice wine bottle shape	1
		Range-hood shape	2
		Regular holes along the top & bottom edges	1
		Regular holes along the top & bottom edges, Regular holes on both side-seams	2
		Stitch pattern sample	17
		Wine bottle shape	1

Applied process mapping of the project

The following Table 23 profiles the project process initially derived from the investigation of emails and the printouts of the emails. The same applied process mapping technique was applied as explained Table 12.

Table 23: The design activity process of Tube sessions 2008 at Curtin

Step №	Verb	Noun/Object	Qualifier
1	Received	an email	from the head lecturer regarding upcoming tube sessions for the next semester
2	Confirmed	previous knit data files	of tube garments 2007
3	Made	yarn arrangement	for students' work
4	Received	acrylic yarn	arrived at DAFWA from interstate
5	Confusion over the yarn order made		acrylic yarn to test prototypes along with wool yarn ordered for students' work at once caused misunderstanding where to invoice which yarn for how much
6	Problem resolved		
7	Wool yarn arrived		at DAFWA from overseas
8	Held	an introductory class	prior to main sessions to do the followings: to distribute two hand-outs to students, to view tube samples (1/4 of the size 8 female body), to request students to work as a pair, to request the students to have a look at the CAD generated stitch patterns book to make selections for their work, to inform the students an email would be sent to students as a reminder before class, and to request the students to send an email including the required information within a week
9	Held	the first session	to show Tube garment made in 2007; to confirm the students' choices of stitch patterns; to lecture on: ① Introduction to WholeGarment® knitting technology, ② Types of knitwear production, and ③ Some practical issues in WholeGarment® knitting technology regarding machine, yarn, and skill and training; to allocate 500g of yarn for each pair; and to request the students to prepare a set of blunt sewing needles, a pair of mini-scissors and other related accessories
10	Held	the second session	to have 5 minute presentation of each pair on tube garment and to have the students document and submit a draft of *design specifications sheet*s
11	Held	the third session	to have the students document and submit the draft of the *design specifications sheet*s
12	Held	the fourth session	to distribute prototype tubes, to demonstrated proper knitwear finishing work (each pair was given her choice of prototype tubes and stitch pattern swatches to confirm her designs and to learn finishing work), and to confirm the design specification sheets
13	Held	the fifth session	to distribute tube garments to each pair and to demonstrate proper ironing.
14	Participated in	assessment	
15	Participated in	professional photo shoot	

Afterword: Personal retrospective field experiences with a group of people in Korean fashion industry

In early 1990s, I had been to Paris as a member of a group to observe fashion industry in France. These were business mission groups funded by the Korean Federation of Textile Industries. Each group was composed of people from various circles in the Korean fashion industry, mainly experienced fashion designers, management and marketing personnel, and professors in the fashion domain. I happen to be involved in the business mission group three times in a row, with different groups of people every three years (1991~1993). These involvements are rare because the majority of companies are reluctant to release employees for long periods of training or any similar sort of activity. They offered me a chance to watch other fashion designers and people from the industry. Some personal insights that stand out from those times are:

- Designers do not seem to like being in the same group with the less experienced, but ironically, the less experienced tend to get excited if they are with the more experienced;
- Designers do not seem to like to share designs with another designer even if in the same group;
- Designers do not seem to be usually interested in seminars, which often focus on discussion. Designers seem to be more activated by hands-on experiences;
- Designers seem to get distracted because they are constantly looking for a source of design; and
- The more skilful the designer is, the less outspoken s/he is. The reverse seems to be true as well.

These insights, which aligns with the 'observed characteristics of designers', (Carr & Pomeroy, 1992 p. 18) offered me a little breathing space when I first encountered experienced fashion designers from other countries. They have not changed in almost twenty years of my experience, regardless of age, gender, or nation.

Appendix 2: Data collection process in detail

- Identifying critical incidents
- Analyzing emails of critical incidents and the emails for each project
- Data collection process of Curtin and DAFWA email accounts
- Data collection process of personal email account

Identifying critical incidents

Critical incidents were identified by conducting a systematic scan of email contents described as following:

1. Sorted the printouts of emails from three e-mail accounts by email subjects and by sender.
2. Arranged the sorted emails by date and time.
3. Conducted a systemic scan of contents to identify critical incidents in each activity.
4. Collected the printouts of identified critical incidents in each activity.
5. Kept the printouts of the critical incidents in separate files according to activity.

Analyzing emails of critical incidents

The following process was used to identify and analyze emails of critical incidents and to analyze the emails for each project. There are twenty (20) steps in the process:

1. The transitions and progress of researcher's involvement in projects were identified by reviewing emails on the DAFWA computer with similar subject lines.
2. Other 'related' activities were identified from residual emails from the above process.
3. Provisional 'titles' were given to email groups and these were then sorted in order.
4. Printouts of emails were scanned in detail and 'critical incidents' were identified
5. Emails held on the Curtin email server and the Empas portal website email server were reviewed to identify 'critical incidents' using the same method.
6. Critical incident emails were printed out from all these sources.
7. Printouts of critical incident emails were arranged by date and time to identify time lines. Note: As much information as possible was kept under provisional titles by scanning emails in detail and by using multiple copies of emails where necessary.
8. By referring to the backup email accounts, twenty-five (25) different kinds of significant activities were identified.
9. Titles were given to each of these 25 activities.
10. Printouts of the critical incident emails were examined across all twenty-five (25) activities to identify which type of activities were most problematic.
11. The researcher's **objectives and aims** for each activity were identified by analyzing the printouts of the critical incident emails.

12. The researcher's **role** for each activity was identified. These roles included the conventional knitwear designer, design consultant, machine operator, programmer, or the stakeholder.
13. Activities were grouped into **categories** defined by the researcher's role.
14. Each of these activity categories was linked to the researcher's **design activities**. The eight semi-commercial knitwear design projects acted as taxonometric 'bridges' that linked all twenty-five activities into sub-systems at the meso-level (see Figure 46).
15. The researcher's individual **studio activities** were identified.

The **design process** of each project was identified using five additional steps:

16. The timeline of the eight projects was drawn. Using this timeline, from three-email accounts the senders of emails for each project were identified.
17. Received emails for each project were sorted and combined into a single integrated email account for each project for further analysis.
18. The received emails for each project were arranged in time order.
19. Taking one project at a time, profiling of the design process using the 'verb + noun + qualifier' combination was undertaken following the received emails in time order. Using this process, all data sources and earlier data analyses were linked together in an integrated fashion into each project.
20. The **design process** of each project was identified from the outcomes of the 'verb + noun + qualifier' activity profiling process supported by the linked data sources. Together these provided the rationale for identifying the design process for each project.

Data collection process of Curtin and DAFWA email accounts

The 'outlook.pst' files from the email account folders at Curtin and at DAFWA were copied. These were located in a hard drive of two computers in [C:\Documents and Settings\syang (name of user folder)\Local Settings\Application Data\Microsoft\Outlook\Outlook.pst]

1. The two separate 'outlook.pst' files were imported into two different folders in the 'Inbox' of Microsoft Office Outlook on a single other desktop computer.
2. The emails in each different folder in the 'Inbox' of Microsoft Office Outlook were sorted by senders' names.
3. New folders for emails from each sender were created and emails copied to them. Thus, these folders contained all activities related to that sender.
4. All the emails in that folder were printed to check for double posting, reviewing each sender's folder, one at a time.

5. Printouts of emails in each folder were reviewed and the printouts were manually laid out to identify appropriate categories in design project terms.

Figure 124 depicts this initial collating process for emails stored at DAFWA and Curtin email accounts.

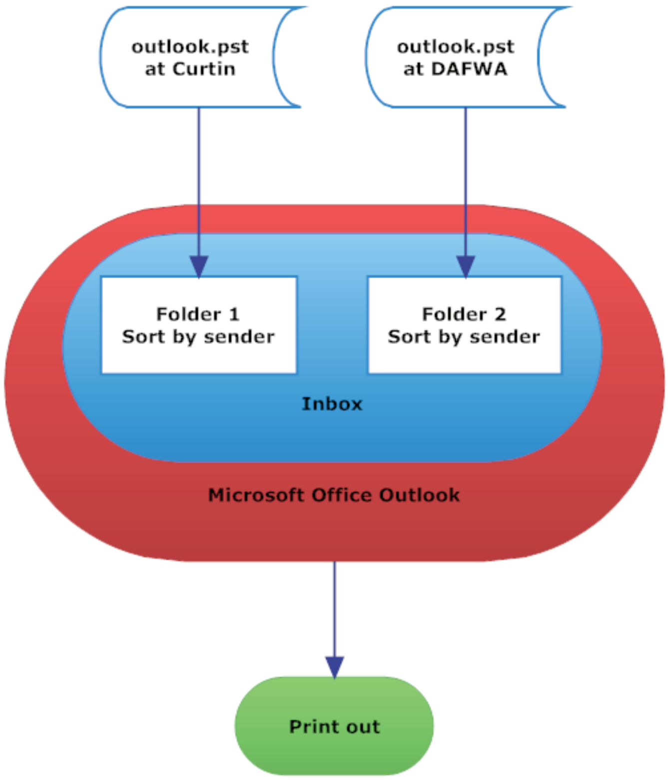


Figure 124: The initial collating process 1

Data collection process of personal email account

A different approach was needed to collate the emails held at the portal website.

1. The emails in the 'Inbox' were searched by each sender's name.
2. The emails in the 'Sent Items' folder were searched by each recipient's name.
3. Emails were selected and saved in a compressed file format, *.tar, once the search was completed
4. Created several and serial *.tar files for each sender's/ recipient's name, occasionally.
5. Each of these *.tar files was copied into the sender's/ recipient's folder sharing the same name as the *.tar file.
6. Each *.tar file was decompressed in its own folder.
7. The decompressed emails were viewed using Microsoft Outlook Express.

8. All emails were printed out and reviewed to check for duplicates
9. The printouts of the emails were reviewed to identify appropriate categories in design project terms.

Figure 125 depicts the second part of initial collating process.

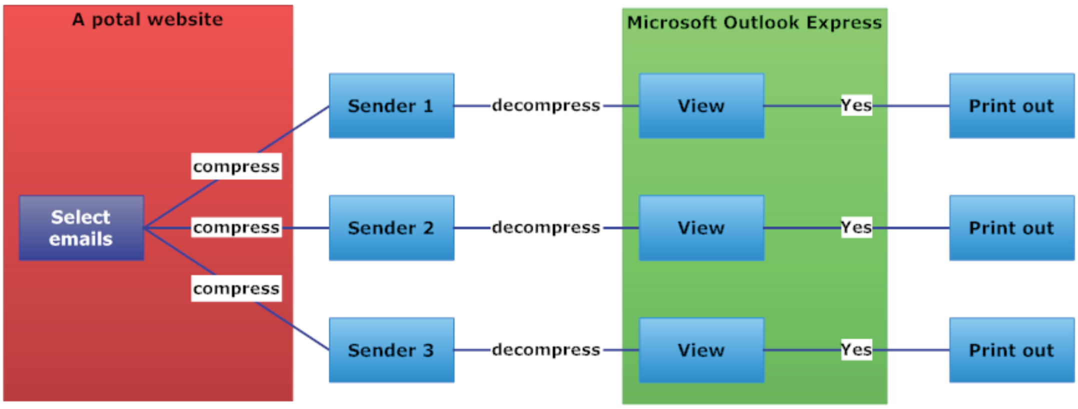


Figure 125: The initial collating process 2

When further analysis was necessary, emails were selected in each sender's/recipient's folder, and the selected emails were sent to the researcher's Microsoft Office Outlook e-mail account (the combined e-mail account) via a Microsoft Outlook Express e-mail client. This was done intentionally to ensure the selected emails were in the same format and structure as the emails from the Curtin and DAFWA email mail boxes.

Appendix 3: Data analysis process in detail

- Data analysis process of knit data files
- Data analysis process of *KnitPaint* design folders of the knit data files

Data analysis process of knit data files

The following eight operational steps were used to create 'file lists of *KnitPaint* design folders':

1. The knit data files categorized in terms of Shima Seiki software file extensions '.000' and '.999' were later copied to a USB drive and combined with relatively recent knit data files for this analysis. These were then copied into a new folder 'AA' on the computer. Many of these data files had been previously stored on 3.5" floppy diskettes and 3.5" magneto-optical discs.
2. Two new sub-folders, '000' and '999' were added to the mother folder 'AA'.
3. Knit data files with '.000' extensions were moved to the '000' folder and files with '.999' extensions to the '999' folder.
4. A count was made of the number of SDS-ONE® *KnitPaint* fabric/garment designs that were actually designed, programmed, and tested on the knitting machine from January 26, 2006 to October 29, 2008.
5. A batch file on Window's Notepad (Programs\Accessories\Notepad) was created to printout the fileslisting list in the '000' folder. The batch file was saved on the same '000' folder (see details for (Foley, 2008)).
6. A fileslisting file was created by double-clicking the batch file.
7. The fileslisting file was saved as a *.txt file.
8. The fileslisting file was printed out.

Data analysis process of *KnitPaint* design folders of the knit data files

The twenty operational steps used were as follows:

1. The saved *.txt file was opened using Microsoft Office Excel.
2. A sheet column with *.000 file extensions was listed by the modified date (oldest on top).
3. Unnecessary columns were deleted.
4. Names of data files on the fileslisting created at Shima Seiki, two data files with no specific name, and duplicated data files were deleted[9].
5. '.000' extension was manually removed from each cell in the sheet column.
6. The fileslisting list was completed with two sheet columns right next to each other: one showing the entire finalized SDS-ONE® *KnitPaint* fabric/garment designs without .000 extensions, and the other displaying the last modified dates.

[9] When eliminating file names on the fileslisting list, the corresponding *KnitPaint* design folder was viewed and occasionally viewed on the 'Picture Directory' to double-check.

7. The fileslisting list was saved as *.xls, Microsoft Office Excel spreadsheet file format.
8. The *.xls file was opened in Microsoft Office Excel.
9. A sheet row on top.
10. On that inserted sheet row, each cell was given a title: ‘Name’ to the sheet column holding entire finalized CAD designs without .000 extensions, ‘Last modified date’ to the sheet column showing the dates, ‘Area (widths)’ to next, ‘Area (lengths)’, ‘Type of knitted designs’, ‘fabric texture layout, ‘pre-registered garment shape used’, and ‘discernible design details’, respectively.

While Microsoft Office Excel was activated:

11. Each CAD design folder of *.000 file was accessed to open its *.dat file.

While the *.dat file in open on *KnitPaint*:

12. Two dimensional (width and length) measurement of design image on the *.dat file was taken using the Shima Seiki function ‘Area’.
13. The measurements from the Shima Seiki ‘Area’ function was recorded on both ‘Area (widths)’ and ‘Area (lengths) columns respectively.
14. The knitted design type was identified and whether it was a 14 or 8 gauge fabric or a WholeGarment®, was recorded by viewing the color (color number) of the design image in the Shima Seiki knit data file.
15. The fabric texture layout type was recorded in terms of whether there was ‘no texture’, ‘textured all-over’, or ‘textured partially’ by viewing the color and referring color number of the design image on the Shima Seiki knit data file of the needle movement.
16. In the case of a WholeGarment®, the type of preregistered garment shape used in its design was recorded. The type of preregistered garment shapes was selected from: flared skirt, pants, sleeveless, sleeveless/flared skirt, S-Paint image, sweater/raglan, sweater/set-in A, sweater/set-in B, and tight skirt.
17. Discernible design details were recorded by examining design CAD images and referring to actual fabric/garment samples and work diaries.
18. The operational steps from # 4 to # 10 were repeated for each finalized CAD design.
19. A sheet column was inserted next to the ‘Name’ sheet column. This sheet column was titled as ‘Studio Activity’, which is now the first sheet column of fileslisting list worksheet.
20. This completed the analysis of the worksheet file.

Appendix 4: Reflections on Shima Seiki Training processes in detail

- The first training
- The second training
- The third training

The first training

Table 24 details the researcher's first training period at Shima Seiki in Japan. Topics marked by question marks (?) were issues or questions raised by her during the course of training.

Table 24: Training in detail

Training schedule		15 days basic knit system programming and 2 days WholeGarment® lessons	
Training mode		One on one	
Course	**Means of training**	**Topics of training**	**Examples of training contents**
Day 1 08/05/2006	Automatic software Note book 1	*Overview of CAD system & knitting machine:* The work flow of making knit data Front & back stitch Color numbers for stitch pattern Original pattern & knit data	
		Color numbers for stitch pattern: Racking	
		Links Process	Link processes of color number 1,2, & 3 Tubular knit Tuck Stitch move – e.g., leaf patterns Knit & cross Relief knit Front & back stitch cross – e.g., diamond patterns
		Fixed Data: Rib pattern Cast-off pattern Auto yarn feeder point	
		Option Line: Option Line function	R1 & R2 jump economizers R3 yarn carrier change R4 knit system choice R5 knit cancel R6 stitch change R8 yarn-in / yarn-out R10 gripper & cutter R11 stitch presser R12 leading stitch cam adjustment L5 carriage speed for knit course L6 carriage speed for transfer course L10 take down for knit course L11 take down for transfer course Pattern development assignment
Day 2 09/05/2006	The basics of shaping pattern	*Shaping:* Widening	Increasing needles Interlock widening Split stitch widening
		Narrowing	A type

			B type Alternate transfer 1 & 2 Partial transfer by option line L1
		Bind-off	Bind-off 1 Bind-off 2 Bind-off 3
		V-neck Round neck Shoulder drop on back	
	SDS-ONE®	*Shaping Set*	
Day 3 10/05/2006	SDS-ONE®	Shaping Set (continued from the previous lesson)	
		Automatic Software Settings	
		How to create an exact size of fabric swatch?	Via S●Paint
Day 4 11/05/2006	SDS-ONE®	Simulation of knitted fabric created in *KnitPaint*	Loop Draw in Design
		Questioning the training schedule	WholeGarment® is all about programming. It takes at least 3 weeks to cover.
		Inside Widening tab	
		A letter to supervisor	
		Shaping again (started 1: 30PM)	
		Function keys	F7 F8 F5
		Slide	Separate
		Shaping Set	Inside widening tab
Day 5 12/05/2006	SDS-ONE®	Shaping Set	Inside widening tab
		Initialize structure	
		Darts	
		Flecharge Knitting	Use of 'short rows'
		Combination of V-neck, waist line (darts), & another stitch pattern	Note data Test_120506
		Stick: Config	Layer View List window>pulldown menu
Day 6 15/05/2006	SDS-ONE®	Check of shaping pattern?	Auto process parameters
		Workflow of creating Jacquard shaping pattern	Help>Knit Menu>*KnitPaint*
		DEV tab	Auto Process Parameters window
		Initialize Structure	
		Shaping Set	
		Color number 201~214	
		Practice: Combination of Rib, All-needle 2 color Jacquard, Plain, 2 color Tubular Jacquard,	Initialize Structure Shaping Set Option Line

		3 color Ladder Back Jacquard, & Plain aligned vertically all-in-one fabric	Jacquard Setting Automatic Software Settings> √ Development Process
Day 7 16/05/2006	SDS-ONE®	Scale-down of Jacquard design?	
		Request to send an email to supervisor?	
		Priority in Shaping	Color number 62, 72, 4/5
		Package: repeat function Need of being even? Not use of color number 6 & 7 for the Package Base Pattern?	
		<u>*Package:*</u>	Package Base Pattern Package Developed Pattern Package File Parameter
		All about drop stitch	
		Package Development	Function tab Shadow tab Composition Color tab
		Package folder where & how?	Make a folder before applying Package Development
		Free Color mode vs. Paint Color mode: Free Color mode	Stitch pattern Jacquard Intarsia
		Paint Color mode	WholeGarment®
Day 8 17/05/2006	SDS-ONE®	Package continued	
		Area window Mode	Direct Structure Package Pattern 1 Dot Free
		Make of modification	Win. Copy window
		Use of Package Base Pattern?	S●Paint window
		Apply & use of Package in *KnitPaint*?	Save in Package File Parameter Use directly on top of Package Base Pattern (Package Development) Apply table in *KnitPaint* Shaping Set>User Package Config
		More Package lessons	
		<u>*Intarsia*</u>	
		Function key	F9
Day 9 18/05/2006	SDS-ONE®	Intarsia continued	
		Multi-load of files	
		Color numbers in use	Edit window>edit>check area
		Knitting tip 1	Avoid tuck stitches on Intarsia
		Workflow of creating Intarsia pattern	Carrier Setting

			Set Time Limit √ Intarsia Type 1
		Knitting tip 2	Remove Yarn-in & Yarn-out manually
		Programming practice: Intarsia Jacquard	
		Possibility of combining Intarsia & Intarsia Jacquard?	Yes, even with complicated designs
		Change from intarsia to Intarsia Jacquard	Field Change
		Adjusted knitting time?	Knit Adjustment>Change Speed>Simulation Start
		Importance of balance among same shapes	
Day 10 19/05/2006	SDS-ONE®	Loop Draw	Design
		Processing Intarsia	
		Change of carriers assigned by computer	
		More on Jacquard & Intarsia Jacquard	Tuck on Front Ladder Backing
		Homework	Stitch pattern + Intarsia Jacquard only Maximum 4 carriers (less is better)
		Know-how to 'jiffy look' stitch pattern	Note data 190506_9_coogi
		View of Knitting Directions	Draw Option Line window>Direction
Day 11 22/05/2006	SDS-ONE®	Package	Free color mode Paint color mode
		Package for WholeGarment®	Paint color mode
Day 12 23/05/2006	SDS-ONE®	Programming practice: Combination of Rib, Tubular, Ladder Back Jacquard, Double Jersey, & Single Jersey aligned vertically all-in-one fabric	Note data 210506_2
	NewSES®183SW	Knitting practise	Note data 210506_1 Note data 210506_2
	SDS-ONE®	Intarsia & Intarsia Jacquard	
		Reason for difficulties in All-needle knitting?	Gap between Front & Back Beds
Day 13 24/05/2006	DSCS instructional manual	*DSCS*	Length of 1 loop Loop screen (see p. 30) Conversion table (see p. 107)
		Set to DSCS mode	
		Threading Mini-tension Disk	
		Stitch Cam	
		Control mode	Note p.18
		Sampling & Compare mode	Note p.19
		Stitch Adjustment	While creating Loop Routine
		Use of Group 2	Rib knitting

		Loop Routine	Sequent / Independent (see p.15)
		Yarn Measurement screen	Note pp. 26~27
		Use of Second Stitch for design?	
		Procedure for inputting Carrier data	Note p. 38
		Texture Sample	Note p. 56
	SDS-ONE®	Second Stitch	
		Sequential Knit	
		Make of big pattern?	Divide designs as top & bottom (use of slit pint)
		Technological questions on designs?	Use of S●Paint drawings Note?
Day 14 25/05/2006	NewSES®183SW	***Knitting practise?***	Second Stitch Loop Routine Texture Sample
		Bind-off with Draw-thread sample?	
	SDS-ONE®	Making Texture Sample	
		To see what kind of Loop Routine?	DSCS menu
	NewSES®183SW	The easiest way to knit something out the machine? Observing the instructor operating the machine	Demonstration of instructor: Loop Routine 2 2nd Stitch (tighter value) Yarn Adjustment Bind-off with draw-thread
	NewSES®183SW Yarn carrier	Yarn Carrier change between the Normal and the Split?	Demonstration of instructor: Yarn Stopper Yarn Guide Needle Pressing Plate Remover
	NewSES®183SW Sinker	Sinker change?	Demonstration of instructor
		Knitting machine maintenance?	Cleaning first Oiling later
	SDS-ONE®	WholeGarment®	S●Paint *KnitPaint*
		Sweater>raglan	
		Change of garment shape	Pre-defined garment modules
		WG knit set	Shaping Set Structure Initialize
		WholeGarment® process in general	New>WG>Sweater>Size Pattern Width Initialize & Outline adjust WG Knit Set S●Paint (blinking)
		Homework	Sweater>raglan>turtle neck
		Use of *KnitPaint*?	Garment shape & stitch pattern variations

		Use of S●Paint	Jacquard & Intarsia
		Programming focused training schedule?	2 weeks of Integral knitting 3 weeks of WholeGarment® 1 week of PGM (patterning)
Day 15 26/05/2006	Knit fixer	Finish of bind-off	Demonstration of a sample make-up staff
	NewSES®183SW	Loop Routine set-up	Demonstration of the instructor
	SDS-ONE®	Use of Draw-thread between fabrics?	Note data 250503_3
		Change of necklines?	WG Knit Set
		Insertion of slits	
		Tight skirt	Make back-drop '0'
		One-piece	Load two WG simultaneously
		Cross-Pair error?	
		Fill of stitch pattern on both front & back simultaneously?	
		Homework	Note data 240506
		Carrier engaged in back knitting?	Auto Parameters>Yarn screen
		Colors used for Option Lines?	Edit>Check Area
		Instructor's recommendation for easier knitting	Leave at least 2 needles on both edges
		Exact size of garment knitting?	Measure large area of sample piece (10cmX10cm)

The second training

Table 25 displays how the second training proceeded.

Table 25: Training in detail

Training schedule		10 day training period and customized lesson schedule with wish list	
Training mode		One-to-one	
Course	**Means of training**	**Topics of training**	**Examples of training contents**
Day 1 09/01/2007	SDS-ONE®	1st **Wish list** V / U necklines, set-in sleeve, & skirt DSCS & Take-down Combine & error messages Slits & pockets	Shaping 3 Machine Adjustment 4 WholeGarment® 1 Integral knitting 2
		When only Fixed Rib exists (without rib)	Use of #30 with Knit Cancel command ☑ Control Simulation
		Examples of stitch formulation	Reverse #40 Normal #6
		Shaping Set>Inside Widening tab	☑ Close Hole ☑ Type 2 All Transfer (when problem occurred, change to 1X1 partial) STP (stitch presser): possibility of yarn breaking when weak yarn used
		Lecture help	Shaping
		Darts	#241 (left) / #242 (right) Open/Close window Slide>Center Line
		Cap	*KnitPaint* Help>Flow of Creating 'Watch Cap' Pattern
		Shaping Set	Cable tab: Relief Knit section>⦿Both Side 1 Course Etc tab: ☑ Special process Before Cable Transfer Back Stitch to Front Neck process>Type 2 Bind-off Type>with Pick-up Stitch Pattern Development>Draw center needle position
		No STP for Rib	
		Create pattern for grading with using the rule formula data on the measurement table data.	Multi Grading window>Rule Formula Grading tab
		Shadow	
		Data copied from desired disk or	Picture Directory window>Device Copy

		folder to desired disk or folder	
		Change of Group Data	Picture Directory window>click right of mouse>Property>Image Property
		Creating fabric: Tubular Pintuck Floating Jacquard	New window>Non-Shaping tab Note data 'floating jacquard' Note data 'WholeGarment® hat' Note data 'darts' Note data 'cap with correct answer' Note data 'interlock pattern' Note data 'pintuck pattern'
Day 2 10/01/2007	SDS-ONE®	Interlock pattern modified	
		Interlock-Tubular Jacquard	Note data 'interlock-tubular jacquard'
		Work flow of Auto Process Parameters	Yarn-in type Setup part Master Rib
		Gauge conversion	Load S●Paint image>Edit window>Kint Edit tab>All Needle 1X1 Conversion button>Select Pattern button>Package Area>Exec
		Knitting Adjustment	
		Mesh Mapping	Mesh Tool Mapping window in Design
		Package	Note *KnitPaint* Help>Package Software Guide>Contents for Basic Lessons>2 color Tubular Jacquard>Package Base Pattern
		Auto Gripper	Gripper & Cutter activated together
		Yarn-out	Carrier move to left
		Make Package	
		Package File Parameter window	Store Directory Auto Entry Package File Name √ Delete Package files in a registration directory √ Package Table Auto Make √ Multiple Store in Area>Bottom Start, X-Direction OK Package Development>Normal tab>Function tab>Shadow tab
		Missed stitch pattern	Note data 'miss_pattern_correct_c5'
		Initial Setting error	Check Carrier
		Package: Registration Option Line 1 Registration Option Line 2 Registration Option Line 3 Registration Option Line 4	 A division in wale direction A number of lines after compression of Package Base Pattern Repetition to wale direction Repetition to regularly direction (bias repeat)
Day 3 11/01/2007	SDS-ONE®	Shadow again	
		Missed stitch pattern without Tuck	Note data 'miss_pattern_wt_tuck'
		Missed stitch pattern with Tuck	Note data 'miss_pattern_w_tuck'

		Mesh pattern	Note data 'cape_mesh_1x1'
		R12 Leading Stitch System Adjustment	Leading Stitch Cam Adjustment Leading Stitch Cam Setting
		Stitch value for Pintuck	
	NewSES®183SW	<u>*Knitting Practise*</u>	Note data 'diamond_pintuck'
	SDS-ONE®	Use of *.999 file	1st same yarn count 2nd same structure
		Load of Knit Data file	1st *. 999 2nd *.000
		Data from instructor	Note data 'body 2'
Day 4 12/01/2007	SDS-ONE®	Get details printed Get *.999 file for fabric	Knitting Adjustment window
		Carrier change	Shaping Set window
		Work flow of Insert description when printing	Knit Type (WG)>New S·WG-V Sleeveless
	NewSES®183SW	<u>*Knitting Practise*</u> Loop Routine 2 screen	Note data 'terry_lace_22 knit'
	SDS-ONE®	Combination of C-Knitting	Not machine-produced look: Bind-off B
		Free Color mode vs. Paint Color mode	
		Modify WG Patterns simultaneously Use of Sync.Draw	Sync.Draw window
		Insert/Delete window	
		Work flow of Package Development	
		C·Knitting	Note data 'c-knitting_vertical_hole' Note data 'c-knitting_vertical_hole_structure' Note data 'c-knitting_vertical_hole_shaped'
		Affine Change window	
		KnitPaint tansform	Note data '*KnitPaint*_transform'
Day 5 13/01/2007	SDS-ONE®	**2nd Wish list**	13 original designs shown to the instructor Technical issues: Pintuck on WholeGarment® Jacquard & Intarsia demonstration Utilizing Test Piece Plating (Plain)
		Camisole	Help file not working: ask Programmer
		Halter	Upside down of both sides slits
		KintPaint-Transform-Ex (delete top)	Originate from Sleeveless A: Bind-off in top, Setup 1 at bottom edge
	NewSES®183SW	<u>*Kitting Practice*</u> Bind-off Problem Yarn Error	Note data 'c-knitting_vertical_hole' Note data 'c-knitting_vertical_hole_structure_modi' Note data 'c-knitting_vertical_hole_shaped_ex' Note data '*KnitPaint*_transform_ex'

	SDS-ONE®	Sync.Draw	
		Programming Practice	Note data 'BODY6'
		How to get right sizes	Test Piece Gauge Input Screen
Day 6 15/01/2007	SDS-ONE®	Load Package Base Pattern on *.dat file	Note data '2slits_garter_edge'
		Use of Second Stitch: Change #1 to#27 & #2 to #28	Note data 'six_holes_garter_edge_2ndStitch' DSCS Menu>2nd Loop Difference
		Work flow of Load Package Base Pattern on *.dat file	Note data 'six_holes_garter_edge__top_2ndStitch_structure'
		R12	Leading Stitch Adjustment
		Take-down: Comb Needle≫Main Roller (in strength)	When Main Roller only When Comb Needle only
		Knit Simulation window>Check	Knit Control>Ω>Main Block>Minimize Screen>*.dat blinking
		Collected data, necessary information of every one course of carriage when knitting with knitting machine	Control>Yes>OK>Block #> Minimize Screen>Cont.Pos (on)/(off)
		Modify mistakes on Package Base Pattern	Edit window>Edit tab>Check Area>#>√ Zoom & Scroll, √ Blink Display>Eliminate R10 #11, #21
		C·Knitting part	Need to be even Knit·Cross (top)/Cross·Knit(bottom)/ Knit·Cross(one row above C·Knitting)
	NewSES®183SW	*Knitting Practise*	Note data '2vertical_slits_garter_edge' Note data '2slits_garter_edge_2ndStitch' Note data 'six_holes_garter_edge__top_2ndStitch_structure'
Day 7 16/01/2007	SDS-ONE®	Use of Carrier #5 on right side when knitting fabric	Note data 'miss_pattern_correct_c5'
		Change of Setup Value	Control Simulation (Ω)
		Caution with Take-down	Note data 'six_holes_garter_edge__top_2ndStitch_structure'
		Positions of C·Knitting: Higher than Slits Same Lower than Slits	Note data '3sides_same' Note data '3sides_same_c_low'
		Technical analysis of 2nd Wish list	
	NewSES®183SW	*Knitting Practise*	Note data 'miss_pattern_correct_c5' Note data '3sides_same' Note data '3sides_same_c_low' Note data '4sides_2holes' Note data '4sides_4holes'
Day 8 17/01/2007	SDS-ONE®	Check: DSCS Menu Yarn Measurement Loop	Note data '4sides_4holes_cape_mesh' & '4sides_4holes_cape_mesh_3sp' (Sea urchin shape)

		Loop Routine 2nd Loop Difference Yarn Stopper	
		Knitting order of Diamond Pintuck	Note data '3sides_c_high_pintuck' Note data 'diamond_pintuck' Note data '4sides_4holes_cape_mesh_3sp'
		Move·Cable Separation in detail for WholeGarment®	
		Stop Knitting Machine	#20 on L7
		Driving & Knitting Time of machine	Admin Data>AD2
		Why Move·Cable Separation?	Note data '4sides_4holes_cape_mesh'
		Programming One & Two-Vertical Slash	New>Non-Shaping>Integrate Note data 'vertical_slit_garter_edge' Note data '2vertical_slits_garter_edge'
	NewSES®183SW	*Knitting Practise*	Note data '4sides_4holes_cape_mesh' Note data '4sides_4holes_cape_mesh_3sp' Note data 'vertical_slit_garter_edge'
Day 9 18/01/2007	SDS-ONE®	**Confirmation of revised Wish List**	Note data '3sides_same_c_low' Note data '2vertical_slits_garter_edge' Note data '3vertical_slits_garter_edge' Note data 'Horizontal_Hole' & 'Horizontal_Hole_porte' Note data 'Flechage_Hole' & 'Flechage_Explanation' Jacquard & Intarsia programming & knitting Plating Utilizing Test Piece
		Work flow of Intarsia programming	New>Non-Shaping>Integrate Note data 'flechage_design_intarsia' Note data 'Konbu_Design' Note data 'Konbu_Intarsia'
		Work flow of Programming One Horizontal Slash	New>Non-Shaping>Integrate Note data '3vertical_slits_garter_edge' Note data 'Horizontal_Hole.dat'
		Work flow of Flecharge knitting	
		1X1 Conversion of Intarsia (Integrate)	Knitting Type: √ 1X1 √ Development Process √ 1X1 conversion
		Conversion of Flecharge design to Intarsia	Note data 'flechage_design_intarsia'
		Work flow of Abnormal Shapes	New>Shaping>√ Size, √ Structure Note data 'Konbu_Intarsia'
		All about Jacquard	Transfer Jacquard: 1X1, Normal Tubular Jacquard 1: in case of 2 color, Front/Back same Tubular Jacquard 2: Front (3 color), Back (2 color 1X1)

			Jacquard with Ladder Backing 1: More than 1X1 Jacquard with Ladder Backing 2: 1X1 Back Floating Jacquard
		Work flow of Programming Floating Jacquard (3 color)	New>Non-Shaping>Jacquard
		Work flow of Programming Transfer Jacquard (2 color)	New>Non-Shaping>Jacquard
	NewSES®183SW	*Knitting Practise*	Note data ‘floating jacquard’ Note data ‘Transfer_JQ’
Day 10 19/01/2007	SDS-ONE®	**Confirmation of finalized Wish List**	
		Knitting order of C·Knitting	Note data ‘3sides_c_high_Pintuck’
		Imposing stitch patterns on Test Piece	
		More on Pintuck Knitting	Use of Speed #3 Note data ‘TP_STRUCTURE_Pintuck3’
		Plating	Note data ‘Plating_1x1’
	NewSES®183SW	*Knitting Practise*	Note data ‘3sides_c_high_Pintuck’ Note data ‘Plating_1x1’
		Email request to the tutor: insufficient time	Note data ‘Konbu_Intarsia’ Temperature of yarn storage room Washing machine & drier details Note data ‘Flechage_Hole’

The third training

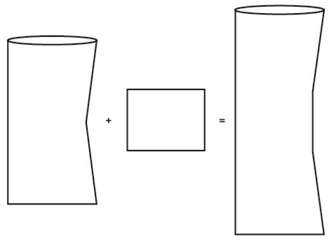
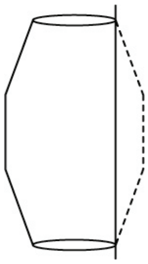
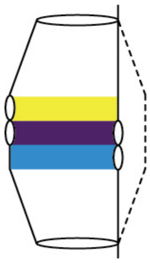
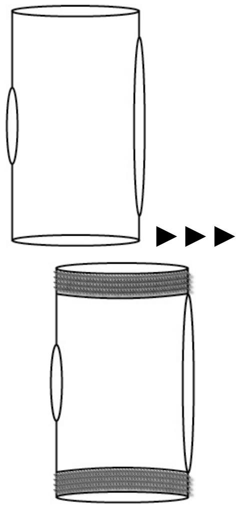
The following Table 26 shows in detail how the third training was progressed.

Table 26: Training in detail

Training schedule		10 day Customized lesson schedule with priority list	
Training mode		One-on-one	
Course	**Means of training**	**Topics of training**	**Examples of training contents**
Day 1 02/07/2007	SDS-ONE®	Work flow of developing 8 gauge fabric	
	NewSES®183SW	<u>*Knitting Practise*</u>	
			1st Loop Value for #5: Body (12), #24: Waste (12), #33: Setup (9), #34: Tubular(12), & #22: Waste (12) Yarn Carrier change as you wish Fabric Take-down Change of Comb Tension Yarn Adjustment>Stroke Adjustment DSCS Menu screen: Loop Routine Yarn Measurement Loop 2nd Fabric Take-down Change of Main Roller value after dropping Comb>stronger
	SDS-ONE®	Two ways of changing drawings	Paint>dual screen mode>Paint User Knit Paint>manually make 2X2 cable: ※D>WG Gen Ref>NewSWG_V> Sweater>Cable
		3X3 Cable vs. 2X2 Cable	
		Manipulating Elastic Hole on Skirt (Predefined garment modules): Hole on left side Hole on right side Holes on both sides	Note data '2007000701-4' Note data '2007000701-5'
		Yarn Carrier Combination Error	
Day 2 03/07/2007	SDS-ONE®	Proper Yarn Count	2/30 & 2/32: 2 ends 2/48: 3 ends 2/52: 3~4 ends
		Yarn Count Conversion	Conversion Table window>Yarn Count
	NewSES®183SW	<u>*Knitting Practise:*</u> Take-down Change of Mode on Loop Rt. Set screen: Reset Loop Length Left side roller	 Note data '20070702-4': unsatisfactory!

		Loop 1 screen: #5 & #6	
		<u>*Knitting Practise continued:*</u> Change Loop Length Loop routine>Second Stitch:⦿S/R DSCS Menu>2ND Loop Difference>#5 & #6: 1mm tighter	Note data '20070702-44': #5: Body (11), #6: Body (11), #9: Below Hole (11), & #10: Hole(12) Note data '20070702-44.999': ※Take-down
	SDS-ONE®	Insert/Delete	
	NewSES®183SW	<u>*Programming & Knitting Practise*</u>	Note data '20070703-1': leave 2 stitches on both side Take-down data '20070702-44.999' used Change of Take-down & Speed Main Roller
	SDS-ONE®	Dealing with Error message	Check box>Load Back screen>click where is seen After-Auto-Process image>Black screen blinking
		Yarn-in/Yarn-out problem	
		Insert/Delete Practise	Note data '20070703-2' with Porte Yarn Porte Yarn: no need of Encoder
		Things to remember when manipulating WG	Specify different carrier – e.g., #5↔#51 Loot at Option Line #3 Copy necessary part Check Yarn-in/Yarn-out
		More tips on manipulation	Note data '20070703-4' ※ D>WG Gen Ref>NewSWG_V>Skirt>2nd_PAK>ADD
Day 3 04/07/2007	SDS-ONE®	Possibility of interlock as WG?	No! Similar look: Seed Stitch
		Technical consultation to the 1st tutor on WG programming	Note data 'master_test7': 103 2nd Loop Difference screen Note data 'master_test88-1': #20 & #29/#30 & #39 seldom used for WG Note data 'master_test1002': OK Note data 'master_test10': OK Note data 'master_test5': 103 2nd Loop Difference screen Note data 'master_test1005': Leave it Note data 'master_test1000': 103 2nd Loop Difference screen
	NewSES®183SW	<u>*Knitting Practise*</u>	Note data '20070704-1' Fixed Rib Data Loop Routine Screen>Loop 1>Loop 2 Loop RT.SET>RT EXEC on Note also data '20070704-22': when Widening, be careful with Yarn Carrier position
		<u>*Knitting Practise continued*</u>	Retry data '20070704-1' to prevent stitch

			dropping: elimination of #52 on #16
	SDS-ONE®	Bind-off & Back Half Tubular	Note data '20070704-3'
		Dealing with Cross Pair Error message	Area window>Structure>OK>Edit tab>Move, Cable Separation>Default>Exec
		Carrier becoming loose before Bind-off>Fabric File-up message	Possible error on Package
	NewSES®183SW	*Knitting Practise*	Note retry of data ''20070704-3': Loop Length #25 (11 to 13) Change length of Back Half Tubular: Economizer (#81: Bind-off, #82: /, #83: \, #88: last part, & #91: last yellow line) Problem on Yarn Carrier #8: try to lessen angle of Yarn Angle Control Arm
Day 4 05/07/2007	SDS-ONE®	Programming Practice on Cross Pair Error	Note data ''20070704-4'
		Kick Back Process?	
	NewSES®183SW	*Knitting Practise*	Note data 'fitted_sweater': change Tuck to Plain under armpit Check use of Sub-roller After Loop Routine, check Drive Information Check Stitch Cam of Front & Back
	SDS-ONE®	Package Development for Beanie in detail (WG hat)	
		Yarn-in/Yarn-out Practice	Note data 'Note data ''20070704-4': keep very first & last only
		WG hat vs. Shaping hat	
		Programming Slashes	Note data '20070705-11' (smaller) Note data '20070705-1' (bigger)
		Priority list	1st: Slashes 2nd: WG hat 3rd: Shaping hat 4th: Pocket 5th: Package Development 6th: Use of 2/48 & 2/52
Day 5 06/07/2007	SDS-ONE®	When several Yarn Carriers stop at the nearest position to each other: Yarn Adjustment	Note data '20070705-1' Option Line L7 #11: page 1 #12: page 2 In case of WG Page 1: before Cuff Page 2: after Set-up Rib Page 3: after Sleeve Joint
	SDS-ONE® & NewSES®183SW	*Programming & Knitting Practise*	
			Note data '20070706-1' with Porte yarn: Size Spec (20070706-1)

		 After S·Paint	
		 On S·Paint	Note data ‘20070706-111’ : still error message
			Note data ‘20070706-11’
	SDS-ONE®	Carrier Combination: assigning different Yarn Carrier to Bind-off	S·Paint>Automatic Software Setting
Review at Nanpuzo 07/07/2007 ~ 08/07/2007	SDS-ONE®		Note data ‘20070706-1111’ See Figure Z for details
Day 6 09/07/2007	SDS-ONE®	Work flow of how to develop S·Paint & *KnitPaint* mixed patterns	Copy of Package File that you need Register Package to Package File Parameter Package Development: to make Front & Back together
		Sync.Draw	Package Area: Insert/Delete
		Move/Cable Separation	

		Assigning Yarn Carrier	
	SDS-ONE® & NewSES®183SW	*Programming & Knitting Practise*	Note data '20070707-11-all-1'
	SDS-ONE®	Use of 'predefined garment modules': Bolero Tip: Modify safe zone!	Note: D>WG G R>NewSES·V>Sweater>QFD>NewSES 14>BO QFD Note data 'bolero' Note data 'bolero2' Note data 'bolero2_mod' Note data 'bolero2_mod_2nd' Note data 'bolero3_2' Note data 'bolero3_2_elong' Note data 'bolero3_2_elong37'
	SDS-ONE®	*Programming* **Work flow of double Package Development**	
			Note data: D>WG G R>NewSES·V>Sweater>QFD>NewSES 14>BO QFD
		Work flow of creating Shaping hat	Note data 'shaping-hat-1' Note data 'shaping-hat-2': Front & Back stuck together Note data 'shaping-hat-3': All Needle Note data 'shaping-hat-3-1x1-NW' Note data 'shaping-hat-3-1x1-W' Note data 'shaping-hat-3-mod'
	SDS-ONE®	Practice on creating Shaping hat	Note data 'shaping-hat-2'
		Review at Nanpuzo	Note data 'shaping-hat-3'
Day 7 10/07/2007	SDS-ONE®	*Programming* Work flow of creating Bolero	
			Note data 'bolero2_mod'
		Work flow of adding Waste	Note data 'shaping-hat-3-1x1-NW'
		Work flow of creating WG hat	Note data 'HD's cap_WG'
Day 8 11/07/2007	SDS-ONE®	Work flow of Cap Widening: to check WG patterns	Note data 'HD's cap_widening'
		Work flow of creating Parachute Sweater	Parachute Setting WG Knit Set Move/Cable Separation
		Work flow of creating Camisole	Note data: D>WG G R>NewSES·V>Slveless>QFD>Norssca.qfd Note data: Help>WG Help>NewSES>Compressed Pattern>Carrier>NewSWG>Camisole>Tank >Top Armhole B
	NewSES®183SW	*Knitting Practise* Parachute Sweater Parachute Sweater again Shaping hat	
			Note data '20070711-1' Note data ''20070712-1' Note data 'shaping-hat-3'
Day 9 12/07/2007	SDS-ONE®	*Programming*	
			Note data 'shaping-hat-3-mod'

		Work flow of creating Set-In B Sweater with C·Knitting	
	NewSES®183SW	*<u>Knitting Practise</u>* Set-In B Sweater with C·Knitting	
			Note data ‘20070712-2’
	SDS-ONE®	Package practice	
Day 10 13/07/2007	SDS-ONE® & NewSES®183SW	*<u>Programming & Knitting Practise</u>* **Use of 2/48 & 2/52**	
			Note data ‘bolero3_2_elong’ Note data ‘bolero3_2_elong37’
	SDS-ONE®	**Work flow of creating Pocket**	Note data ‘20070712-2w-pocket’
		How to copy Bind-off from another file	Note data ‘Flechage_Hole_Bindoff’ from 2nd training

Appendix 5: Research activity analysis in detail

- Identifying twenty-five activities
- Objectives/Aims of the researcher in each activity
- Roles of the researcher in each activity
- Categories of activities
- Projects
- Studio activities
- Knitted designs
- Types of knitted designs
- Types of fabric texture layout
- Types of pre-registered garment shapes used to develop WholeGarment® designs
- Types of discernible design details for each studio activity
- 114 numbers of discernible design details
- Findings from different types of data: example/s of similar design steps in each project

Identifying twenty-five activities

The researcher undertook twenty-five (25) activities. These separate activities/tasks were identified from emails for each activity. Table 27 shows the title, the start/end dates, and days of duration. The start date was the date of the first email that was initially received regarding the activity. The end date was the last date an email was delivered regarding the activity. All activities in Table 27 are chronogically listed according to end date. The duration includes the start and end date and is calculated using the *Time and Date* software (2009).

Table 27: Twenty-five activities in detail

Activity №	Title of Activity	Start date	End date	Duration (Day/s)
1	Initial involvement with DAFWA	21/09/2005	24/01/2006	126
2	Belmont Design Edge seminar	27/02/2006	28/04/2006	61
3	Training at Shima Seiki (1st)	08/05/2006	09/06/2006	33
4	Technician's visit (1st)	18/06/2006	22/06/2006	5
5	Seminar for TAFE students	10/06/2006	22/06/2006	13
6	'Design for Comfort'	24/01/2006	11/07/2006	169
7	Dust issue	08/11/2006	13/11/2006	6
8	Training at Shima Seiki (2nd)	09/01/2007	19/01/2007	11
9	IP situation	03/10/2006	20/02/2007	141
10	Knitting machine demonstration for students from Narrogin Agricultural College	13/03/2007	14/03/2007	3
11	'Wagin Woolorama Ambassador 2007'	31/01/2007	12/04/2007	72
12	Cone-shaped artifact	28/02/2007	17/04/2007	49
13	Knitting machine demonstration for Iraq customers of DAFWA	01/05/2007	07/05/2007	7
14	The Bird Flu issue	03/05/2007	17/05/2007	15
15	Training at Shima Seiki (3rd)	02/07/2007	13/07/2007	12
16	Sourcing yarn from overseas	28/03/2007	06/09/2007	163
17	Technician's visit (2nd)	10/09/2007	10/09/2007	1
18	Seminar for TAFE students	04/09/2007	14/09/2007	11
19	Employment and business case at DAFWA	19/05/2007	29/09/2007	134
20	Tube sessions 2007 at Curtin University of Technology	04/09/2007	30/10/2007	57
21	Knitwear design using Merino Soul's yarn	21/10/2007	20/12/2007	61
22	Professional Practicum 390	02/03/2008	19/04/2008	49
23	Technician's visit (3rd)	10/06/2008	11/06/2008	1
24	Dance Performance at the Livestock Updates 2008	26/04/2008	01/07/2008	67
25	Tube sessions 2008 at Curtin University of Technology	03/09/2008	29/10/2008	57

Objectives/Aims of the researcher in each activity

Each activity had multiple objectives and aims. The researcher's objective/aim for each activity was investigated by mapping them out from emails as shown in the left hand side of Figure 126. This led to identify the researcher's role for each activity as shown in Table 28.

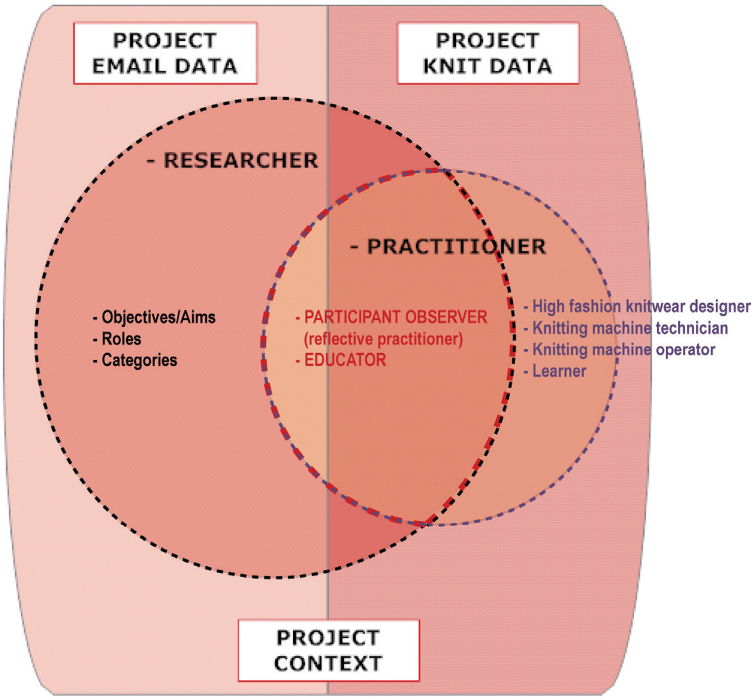


Figure 126: Research activity analysis and data collection

Table 28: Objective/Aim

№	Activity	Objectives/Aims
1	Initial involvement with DAFWA	To develop a potential research project for PhD
		To get access to the Shima Seiki WholeGarment® knitting system at DAFWA to support the research proposal
2	Belmont Designedge seminar	To show seamless knitwear technology 'in action'. Explain briefly how to apply designs to utilize this technical advancement in customizing wool knitwear during Belmont Designedge Innovation Festival as guest speaker
3	Training at Shima Seiki (1st)	To be trained as a knitting machine technician starting with preliminary knowledge of the WholeGarment® knitting machine and basic technical skills
		To be trained as a knitwear designer with understanding and thorough knowledge of SDS-ONE® CAD system
4	Technician's visit (1st)	To upgrade the CAD system and the knitting machine software to Version A48
		To have a short training on some technical issues in programming and operating the knitting machine

		To operate the knitting machine following the technical specifications from Shima Seiki
5	Seminar for TAFE students	To show the WholeGarment® knitting technology 'in motion'. To explain briefly how to apply designs to utilize this technical advancement in new knitwear design, customizing knitwear, knitwear production[10]
6	'Design for Comfort'	To work with five Western Australian designers to develop customized knitted fabrics for them, which were created on the Shima Seiki WholeGarment® knitting machine at DAFWA and also from specially selected WA wool fiber (DAFWA, 2006) for 'Design for Comfort' project which led to the exhibition and fashion show
7	Dust issue	To identify whether there was a problem in breathing in wool particles or dust from fine micron wool yarn and whether it could cause harm to the knitting machine operator occupational and safety issue with Shima Seiki
8	Training at Shima Seiki (2nd)	To be trained as more of a designer-technician who was willing to take the part of programming role
9	IP situation	To discontinue the research while formalizing the relationship between Curtin and DAFWA with respect to the PhD project.
10	Knitting machine demonstration for students from Narrogin Agricultural College	To set up the knitting machine half way through knitting something to show the machine 'in motion'
11	'Wagin Woolorama Ambassador 2007'	To create WholeGarment® outfits for the Woolorama Ambassador of year 2007
12	Cone-shaped artifact	To create a 9M cone-shaped knitted artifact for display at Burswood Casino
13	Knitting machine demonstration for Iraq customers of DAFWA	To set up the knitting machine having already half knitted a garment. That way the machine could be restarted anytime and people could watch the machine 'in motion', and also the drop-off of the garment from the machine
14	The Bird Flu issue	To be unable to receive a few wool sample cones sourced from the overseas yarn supplier
15	Training at Shima Seiki (3rd)	To be trained as a knitting machine technician with intermediate level of knowledge and technical skills on the WholeGarment® knitting machine
		To be trained as more of a designer-technician who was willing to take part of programming role
16	Sourcing yarn from overseas	To identify a suitable overseas yarn supplier with whom to have a longer term primary yarn relationship due to the discontinuation of yarn and other consumables over the IP issue
17	Technician's visit (2nd)	To upgrade the CAD system and the knitting machine software to A52
		To have a consultation and receive advice on some technical issues in programming and operating the knitting machine
18	Seminar for TAFE students	To demonstrate the WholeGarment® knitting technology 'in motion' and discuss its current application to the design industry
19	Employment and business case at DAFWA	To work out a business plan for the Shima Seiki knitting machine, in other words, to write up a business case to justify creating a position for SY at DAFWA

[10] For TAFE students, focus was on knitwear manufacturing rather than knitwear design.

20	Tube sessions 2007at Curtin University of Technology	To explore applying WholeGarment® knitting technology to students' design practices
21	Knitwear design using Merino Soul's yarn	To develop fabrics and WholeGarment® using 'Merino Soul', a new type of 100% Western Australian Merino wool yarn, using Shima Seiki knitting machine at DAFWA in collaboration with an Italian designer.
22	Professional Practicum 390	To provide the students majoring in fashion and textile design at Curtin University of Technology with a practical and a short-term internship in some aspect of professional art practice
23	Technician's visit (3rd)	To upgrade the CAD system and the knitting machine software to A58
		To have a consultation and receive advice on some technical issues in programming and operating the knitting machine
24	Dance Performance at the Livestock Updates 2008	To present tube garments via dance performance at a conference on the evening of July 1, 2008 at The University Club of Western Australia
25	Tube sessions 2008 at Curtin University of Technology	To apply WholeGarment® knitting technology to the students' design practices

Roles of the researcher in each activity

After reviewing the researcher's objectives/aims in Table 28, the researcher's roles for each activity were identified. These are listed in Table 29 as:

- Conventional knitwear designer;
- Design consultant;
- Design consultant/programmer/machine operator;
- Machine operator;
- Machine operator/speaker;
- Programmer/machine operator; and
- Stakeholder.

Table 29: Role

№	Activity	Roles
1	Initial involvement with DAFWA	Stakeholder
2	Belmont Designedge seminar	Machine operator & speaker
3	Training at Shima Seiki (1st)	Programmer & Machine operator
		Conventional knitwear designer
4	Technician's visit (1st)	Stakeholder
		Machine operator
		Design consultant & Programmer
5	Seminar for TAFE students	Machine operator & speaker
6	'Design for Comfort'	Design consultant, Programmer, & Machine operator
7	Dust issue	Stakeholder
8	Training at Shima Seiki (2nd)	Design consultant, Programmer, & Machine operator

9	IP situation	Stakeholder
10	Knitting machine demonstration for students from Narrogin Agricultural College	Machine operator
11	'Wagin Woolorama Ambassador 2007'	Design consultant, Programmer, & Machine operator
12	Cone-shaped artifact	Design consultant, Programmer, & Machine operator
13	Knitting machine demonstration for Iraq customers of DAFWA	Machine operator
14	The Bird Flu issue	Stakeholder
15	Training at Shima Seiki (3rd)	Programmer & Machine operator
		Design consultant, Programmer, & Machine operator
16	Sourcing yarn from overseas	Stakeholder
17	Technician's visit (2nd)	Stakeholder
		Design consultant & Programmer
18	Seminar for TAFE students	Machine operator & speaker
19	Employment and business case at DAFWA	Stakeholder
20	Tube sessions 2007 at Curtin University of Technology	Design consultant, Programmer, & Machine operator
21	Knitwear design using Merino Soul's yarn	Design consultant, Programmer, & Machine operator
22	Professional Practicum 390	Design consultant, Programmer, & Machine operator
23	Technician's visit (3rd)	Stakeholder
		Design consultant & Programmer
24	Dance Performance at the Livestock Updates 2008	Design consultant, Programmer, & Machine operator
25	Tube sessions 2008 at Curtin University of Technology	Design consultant, Programmer, & Machine operator

Categories of activities

The researcher's each activity was categorized into several different groups: demonstration (demo), event, issue, project, seminar, technician's visit, and training.

'***Demo***' is when the researcher showed people how the Shima Seiki WholeGarment® system is used to design and knit garments. People were mostly interested in when they viewed WholeGarment® knitting machine. The audience in general is only interested in the garments. Interestingly, most people were uninterested after 20 seconds of watching the knitting carrier going from side to side.

'***Event***' is a single clearly bounded situation with defined time boundaries and important in respect of the PhD research.

'***Issue***' was an idea or a topic of concern that emerged from an activity.

'***Project***' is a bounded activity that demanded a combination of the three roles of knitwear designer, knitting machine technician, and knitter.

'***Seminar***' was an event in which the researcher explained and demonstrated how the knitting system worked.

'***Technician's visit***' is a visit for repair and update of the Shima Seiki WholeGarment® knitting system by the Melbourne Shima Seiki technician (there is no technician support within Western Australia). The technician also provided technical advice on knit programming. In the technician's visits, the researcher worked with the technician on a specific task list based on her own design work. It was a good opportunity to be able to watch and learn from an experienced technician how to deal with technical issues that fashion designers face in using the Shima Seiki.

'***Training***' refers to the researcher's training and education at the Shima Seiki training courses in Japan. The researcher found this education valuable and feel that she would have wished for more time allocation with the individual Shima Seiki tutors.

Projects

Projects were the researcher's crucial activities that link all other research activities with studio activities, which involved design practices using the Shima Seiki WholeGarment® knitting system. Projects were categorized based on analysis of emails as shown in Table 30 where the projects are highlighted.

Table 30: Category of each activity

Activity №	Title of Activity	Category
1	Initial involvement with DAFWA	Event
2	Belmont Design Edge seminar	Seminar
3	Training at Shima Seiki (1st)	Training
4	Technician's visit (1st)	T. Visit
5	Seminar for TAFE students	Seminar
6	'Design for Comfort'	Project
7	Dust issue	Issue
8	Training at Shima Seiki (2nd)	Training
9	IP situation	Issue
10	Knitting machine demonstration for students from Narrogin Agricultural College	Demo
11	'Wagin Woolorama Ambassador 2007'	Project
12	Cone-shaped artifact	Project
13	Knitting machine demonstration for Iraq customers of DAFWA	Demo
14	The Bird Flu issue	Issue
15	Training at Shima Seiki (3rd)	Training
16	Sourcing yarn from overseas	Issue
17	Technician's visit (2nd)	T. Visit
18	Seminar for TAFE students	Seminar
19	Employment and business case at DAFWA	Issue

20	Tube sessions 2007 at Curtin University of Technology	Project
21	Knitwear design using Merino Soul's yarn	Project
22	Professional Practicum 390	Project
23	Technician's visit (3rd)	T. Visit
24	Dance Performance at the Livestock Updates 2008	Project
25	Tube sessions 2008 at Curtin University of Technology	Project

Studio activities

Eighteen (18) different studio activities were identified from the eight (8) semi-commercial projects with one pre-design development process when they were analyzed in detail. Examining the data file names and their last modified dates of the printouts of knit data files revealed the timing of projects and transition from one project to another. Table 31 shows the sequence which matches the sequence of eight projects drawn from email investigations shown in Table 30 above. Each involved different step of knit/knitwear development process.

The researcher's interaction with others was analyzed to investigate the studio activity procedures involved and their significance in knitwear development processes. Interaction is critical in design processes to complete tasks in one or another.

Another nine (9) studio activities were disregarded in this analysis because these involved no clear distinction to next steps since they were the researcher's own design developments. Those excluded studio activities were seven (7) of the researcher's own design development practice and two (2) studio activities involved in the researcher's earlier Master's research (whose data was still stored in the knitting studio's computer systems).

Table 31: The eighteen studio activities

№	Studio activity
1	Pre-design development for 'Design for comfort'
2	Design for comfort
3	Own design development practice 1
4	'Wagin Woolorama Ambassador 2007'
5	Own design development practice 2
6	Cone-shaped artifact
7	Stitch pattern and garment shape development for Master's
8	Own design development practice 3
9	Master's
10	Tube sessions 2007 at Curtin University of Technology
11	Own design development practice 4
12	Knitwear design using Merino Soul's yarn

13	Professional Practicum 390
14	Own design development practice 5
15	Dance Performance at the Livestock Updates 2008
16	Own design development practice 6
17	Tube sessions 2008 at Curtin University of Technology
18	Own design development practice 7[11]

Knitted designs

The researcher counted the creation of six-hundred and thirty-four (634) CAD designs from January 26, 2006 to October 29, 2008. Eighty-one (81) designs that were not taken into consideration of the actual knitting process were discarded from this analysis. Those were regenerations of the originals or the ones that were tried simply out of curiosity, whether or not they were programmable.

Five-hundred and fifty-three (553) designs were secondly counted. Twenty-two (22) data files were again eliminated. These files were: three files created at Shima Seiki, two files with no specific names, and seventeen duplicated files.

There were finally five-hundred and thirty-one (531) designs that were programmed and knitted on the knitting machine from January 26, 2006 to October 29, 2008.

Table 32 lists the number of designs created, programmed, and actually knitted for each studio activity:

Table 32: Number of knitted designs for each studio activity

№	Studio activity	Number of knitted designs
1	Pre-design development for 'Design for comfort'	18
2	Design for comfort	28
3	Own design development practice 1	56
4	'Wagin Woolorama Ambassador 2007'	15
5	Own design development practice 2	3
6	Cone-shaped artifact	11
7	Stitch pattern and garment shape development for Master's	34
8	Own design development practice 3	12
9	Master's	57
10	Tube sessions 2007 at Curtin University of Technology	64
11	Own design development practice 4	32
12	Knitwear design using Merino Soul's yarn	57
13	Professional Practicum 390	9
14	Own design development practice 5	40

[11] Own design development practice 7 was performed while the tube session 2008 was in progress.

15	Dance Performance at the Livestock Updates 2008	14
16	Own design development practice 6	18
17	Tube sessions 2008 at Curtin University of Technology	58
18	Own design development practice 7	5
	Number of knitted designs in total	**531**

Types of knitted designs

The following Table 33 shows the type of knitted work produced for each studio activity and its reference number created on the CAD system. Numbers in brackets ([ ]) show designs with empty folders that have existing samples. There were twenty-one (21) designs with samples and no design data. Thirteen (13) designs out of the five-hundred and thirty-one (531) designs were indicated as 'null' because they have empty folders and no samples.

Three-hundred and nineteen (319) designs were developed using the WholeGarment® facility. In addition, there were designs created on the WholeGarment® knitting machine without using the WholeGarment® facility. Eighty-four (84) of these designs were of 14 gauge fabric, and one-hundred and fifteen (115) designs were of 8 gauge fabric.

Table 33: Types of knitted designs

№	Studio activity	Fabric 14GG	Fabric 8GG	Whole Garment®	Null
1	Pre-design development for 'Design for comfort'	17	0	0	1
2	Design for comfort	28	0	0	0
3	Own design development practice 1	17	0	33	6
4	'Wagin Woolorama Ambassador 2007'	0	0	14	1
5	Own design development practice 2	1	1	1	0
6	Cone-shaped artifact	0	0	11	0
7	Stitch pattern and garment shape development for Master's	0	7[7]	26	1
8	Own design development practice 3	0	0	12	0
9	Master's	0	0	57[1]	0
10	Tube sessions 2007 at Curtin	0	0	64	0
11	Own design development practice 4	13	8[8]	7	4
12	Knitwear design using Merino Soul's yarn	2	37[2]	18	0
13	Professional Practicum 390	0	3	6	0
14	Own design development practice 5	0	38[3]	2	0
15	Dance Performance at the Livestock Updates 2008	3	0	11	0
16	Own design development practice 6	3	7	8	0
17	Tube sessions 2008 at Curtin	0	9	49	0
18	Own design development practice 7	0	5	0	0
	Sub total	84	115	319	13

Total	**531**

Types of fabric texture layout

Table 34 shows that there were one-hundred and thirty-four (134) pieces with plain texture, two-hundred and nineteen (219) pieces with all-over texture, one-hundred and sixty-five (165) pieces with partial texture, and thirteen (13) missing pieces, in total five-hundred and thirty-one (531) pieces. The table also shows there were not huge differences, when applying textures to fabrics or WholeGarment® patterns, but still shows that there were much more frequent applications of 'textured all-over' than that of 'no texture-plain'.

Table 34: Types of fabric texture layout

№	Studio activity	No texture - plain	Textured all-over	Textured partially	Null
1	Pre-design development for 'Design for comfort'		16	1	1
2	Design for comfort		28		0
3	Own design development practice 1	13	21	16	6
4	'Wagin Woolorama Ambassador 2007'	1	3	10	1
5	Own design development practice 2	3			0
6	Cone-shaped artifact	11			0
7	Stitch pattern and garment shape development for Master's	1		32	1
8	Own design development practice 3		1	11	0
9	Master's			57	0
10	Tube sessions 2007 at Curtin	25	31	8	0
11	Own design development practice 4	8	20		4
12	Knitwear design using Merino Soul's yarn	47	5	5	0
13	Professional Practicum 390		3	6	0
14	Own design development practice 5	3	25	12	0
15	Dance Performance at the Livestock Updates 2008	3	9	2	0
16	Own design development practice 6	6	12		0
17	Tube sessions 2008 at Curtin	13	40	5	0
18	Own design development practice 7		5		0
	Sub total	134	219	165	13
	Total				**531**

Types of pre-registered garment shapes used to develop WholeGarment® designs

Table 35 shows the types of pre-registered garment shapes and another software feature used to develop three-hundred and nineteen (319) WholeGarment® designs out of five-hundred and thirty-one (531) designs. Eight (8) different types of pre-registered garment shapes and the S•Paint program were used. These were: three (3) types of bottoms, five (5) types of tops, and the S•Paint program which enabled development of seven (7) different S•Paint image garment shapes.

In order of use, the pre-registered tight skirt shape was outstandingly used for WholeGarment® knitwear development. The sleeveless top shape followed the next and then raglan sweater shape.

Table 35: Types of pre-registered garment shapes used to develop WholeGarment® designs

	Flared skirt	Pants	Sleeve-less top	Sleeve-less & Flared skirt	Sweater /Raglan	Sweater /Set-in A	Sweater /Set-in B	Tight skirt	S•Paint image	**Total**
1										**0**
2										**0**
3			14	1	16	1		1		**33**
4			4	2				8		**14**
5	1									**1**
6								11		**11**
7								26		**26**
8			8		4					**12**
9			57							**57**
10								64		**64**
11								7		**7**
12	6		4		6		1	1		**18**
13			6							**6**
14								2		**2**
15		8						3		**11**
16		5						3		**8**
17	3		1					38	7	**49**
18										**0**
Total	**10**	**13**	**94**	**3**	**26**	**1**	**1**	**164**	**7**	**319**

Types of discernible design details for each studio activity

There were three-hundred and sixty-four (364) pieces of discernable designs identified out of five-hundred and thirty-one (531) pieces. The discernible design details were the ones with defined design purposes (Table 36). One-hundred and fourteen (114) discernible design details or combinations of them were programmed and knitted for them (see the one after the next, Table 37).

Table 36: Type of discernible design details

№	Studio activity	Discernible design details	№ of the discernible/s
1	Pre-design development for 'Design for comfort' (0)	None	0
2	Design for comfort (9)	No repeat pattern	8
		Fabric texture caused by technically wrong programming	1
3	Own design development practice 1 (18)	2x2 stitch pattern (all-over)	3
		Bind-off	1
		C-knitting	1
		Elongated torso	9
		Neckband	4
4	'Wagin Woolorama Ambassador 2007'(13)	2x2 stitch pattern all-over	3
		Textured from below bust	2
		Textured from below darts	8
5	Own design development practice 2 (2)	Bind-off	1
		Beanie programming	1
6	Cone-shaped artifact (10)	Fibonacci numbers applied to extreme measurement (successful at 8th)	8
		Use of fluorescent yarn	2
7	Stitch pattern and garment shape development for Master's (31)	1x1 stitch pattern	2
		2x2 stitch pattern	1
		Only sample present	7
		Patterned	20
		Tubular shape	1
8	Own design development practice 3 (6)	Textured from below bust	1
		Cap sleeve	2
		Garter stitch pattern all-over	1
		Neck band	2
9	Master's (57)	Stitch pattern combination	57
10	Tube sessions 2007 at Curtin (28)	Border repeat, borders	3
		Patterned except specific part	1
		Stitch pattern combination	13
		Patterned (1 only sample present)	4
		Patterned only in the center	1
		Data from prototype	3
		regular holes along the top & bottom edges	3

11	Own design development practice 4 (19)	Garter stitch pattern all-over	3
		Garter & another stitch pattern combination	3
		Stitch pattern combination	3
		Floating jacquard	1
		Ladder back jacquard	2
		Transfer jacquard	7
12	Knitwear design using Merino Soul's yarn (44)	Stitch pattern combination of 2x2 & plain	5
		Cap sleeve	1
		Elongated body	1
		Elongated body & cap sleeve	2
		Elongated body & long sleeve	1
		Elongated body & neckband	2
		Elongated body & sleeve	1
		Elongated neckband	1
		Elongated sleeve	1
		Floating jacquard	1
		Imitation of vertical fold	13
		Imitation of vertical fold, mirrored	1
		Horizontal tubular strip	1
		Tubular strip with jump economizer	12
		Tubular strip in pyramid shape	1
13	Professional Practicum 390 (7)	1 pattern	1
		Stitch pattern combination of 2x2, garter, & plain	1
		Stitch pattern combination of 2x2, plain, & garter	1
		Stitch pattern combination of garter, 2x2, & plain	1
		Stitch pattern combination of garter, plain, & 2x2	1
		Stitch pattern combination of plain, 2x2, & garter	1
		Stitch pattern combination of plain, garter, & 2x2	1
14	Own design development practice 5 (37)	10-repeat long, width narrowed, but bind-off problem (only sample present)	1
		1x1, bind-off, J's request	1
		2 slits in one panel	2
		8-repeat long. Suitable for the promotional item	1
		Alternation of front & back stitch pattern	9
		Bind-off problem	1

		Cable stitch pattern	1
		Cable stitch pattern, bind-off problem	3
		Cable stitch pattern, DSCS off	1
		Cable stitch pattern, only the first sample successful	1
		Cable stitch pattern, pocket 3 type bind-off	1
		Double-jersey, bind-off, J's request	1
		Interlock, bind-off, J's request	1
		Unsuccessful exaggeration	1
		Improper finishing	1
		Pocket variation: OK	1
		Pocket variation: unsuccessful (1 only sample present)	7
		Pocket variation: regular holes along the top edge	1
		Pocket variation: problem resolved	1
		Panel width OK, but bind-off problem (only sample present)	1
15	Dance Performance at the Livestock Updates 2008 (14)	2x2 stitch pattern	7
		2x2 stitch pattern, holes along side-seam, border at hem	1
		Double-jersey, jump economizer	1
		Reproduction	3
		Tubular strip, jump economizer	2
16	Own design development practice 6 (15)	Frill height variation: 12 rows	1
		Frill height variation: 24 rows	1
		Frill height variation: 4 rows	1
		2x2 stitch pattern, holes along side-seam	1
		Alternation of front & back stitch pattern, holes along side-seam	1
		Bind-off problem	2
		Bind-off problem, alternation of front & back stitch pattern	1
		Bind-off problem, Cable stitch pattern	1
		Stitch pattern combination	3
		Request: plain stitch pattern/plating/special type of yarn	3
17	Tube sessions 2008 at Curtin (49)	1x1 stitch pattern, regular holes along the top edge	1
		2 slits in one panel	5
		2x2 stitch pattern	1
		2x2 stitch pattern only in abdominal region	1

		3 slits in one pattern	1
		Area measurement of compressed pattern	1
		Area measurement of compressed pattern, hexagon shape	3
		Area measurement of compressed pattern, originally barrel shape	2
		Border as pattern	1
		Border on top and bottom	1
		Stitch pattern combination	2
		Stitch pattern combination, area measurement of compressed pattern, hexagon shape	1
		Female bottle shape	1
		Inserted cutting lines for dye swatches	1
		Narrowed range-hood shape	1
		Octagon shape	2
		Ice wine bottle shape	1
		Range-hood shape	2
		Regular holes along the top & bottom edges	1
		Regular holes along the top & bottom edges, Regular holes on both side-seams	2
		Stitch pattern sample	17
		Wine bottle shape	1
18	Own design development practice 7 (5)	Alternation of front & back stitch pattern	1
		Alternation of front & back stitch pattern, bind-off OK: S's	1
		A special stitch pattern	2
		A special stitch pattern, jump economizer	1
		Total	**364**

114 numbers of discernible design details

The 114 discernible design details in Table 37 below were analyzed to find out the technical skills that needed to be learned from residential technician training and self-taught via reviews and own practice to reach a certain degree of competency level.

Table 37: 114 numbers of discernible design details

№	**Discernible design details**	**№ of the discernible/s used in studio activities**
1	10-repeat long, width narrowed, but bind off problem	1
2	12 rows of frill height	1

3	1x1	2
4	1x1, bind-off, J's request	1
5	1x1, regular holes along the top edge	1
6	2 slits in one panel	7
7	24 rows of frill height	1
8	2x2	15
9	2x2 stitch pattern only in abdominal region	1
10	2x2, holes alongside-seam	1
11	2x2, holes alongside-seam, border at hem	1
12	2x2-garter-plain	1
13	2x2-plain-garter	1
14	3 slits in one panel	1
15	4 rows of frill height	1
16	8-repeat long. suitable for the promotional item	1
17	alternation of front & back stitch pattern	10
18	alternation of front & back stitch pattern, bind-off OK: seki's	1
19	alternation of front & back stitch pattern, holes along side-seam	1
20	area measurement of compressed pattern	1
21	area measurement of compressed pattern, hexagon shape	3
22	area measurement of compressed pattern, originally barrel shape	2
23	beanie programming	1
24	below bust	3
25	below darts	8
26	bind-off problem	2
27	bind-off	2
28	bind-off problem, alternation of front & back stitch	1
29	bind-off problem, cable	1
30	bind-off problem, shawl_miss_new_latest	1
31	border as pattern	1
32	border on top and bottom	1
33	border repeat	1
34	borders	2
35	cable	1
36	cable, bind off problem	3
37	cable, DSCS off	1
38	cable, only the first sample successful	1
39	cable, pocket 3 type bind off	1
40	cap sleeve	3
41	c-knitting	1
42	double-jersey, bind-off, J's request	1

43	double-jersey, jump economizer	1
44	elongated	9
45	elongated body	1
46	elongated body & cap sleeve	2
47	elongated body & long sleeve	1
48	elongated body & neckband	2
49	elongated body & sleeve	1
50	elongated neckband	1
51	elongated sleeve	1
52	except bottom of sleeves (severe angle)	1
53	female wine bottle shape	2
54	Fibonacci number	7
55	floating jacquard	2
56	fluorescent yarn	1
57	fluorescent yarn, working but not closing	1
58	garter & another, stitch pattern combination	3
59	garter stitch all-over	4
60	garter-2x2-plain	1
61	garter-plain-2x2	1
62	horizontal tubular strip	1
63	imitation of vertical fold	13
64	imitation of vertical fold, mirrored	1
65	improper finishing	1
66	inadequate exaggeration	1
67	inserted cutting lines for dye swatches	1
68	interlock, bind-off, j's request	1
69	ladder back jacquard	2
70	move1-25	2
71	move1-25, jump economizer (3)	1
72	narrowed range-hood shape	1
73	neckband	6
74	no repeat (1 unit)	9
75	octagon shape	2
76	only sample present	7
77	panel width OK, but bind off problem	1
78	patterned	81
79	patterned center strip	1
80	pencil shape	1
81	plain-2x2-garter	1
82	plain-garter-2x2	1

83	pocket variation	1
84	pocket variation: OK	1
85	pocket variation: original+40 X axis/original+240 Y axis	1
86	pocket variation: original+40 X axis/original+240 Y axis: change color 14 to 13 on L7	1
87	pocket variation: original+40 X axis/original+240 Y axis: in need of fastening holes	1
88	pocket variation: original+40 X axis/original+240 Y axis: in need of pocket modification	1
89	pocket variation: original+48 X axis/original+80 Y axis	1
90	pocket variation: problem resolved	1
91	pocket variation: regular holes along the top edge	1
92	pocket variation: stuck	1
93	prototype	3
94	prototype, regular holes along the top & bottom edges	1
95	range-hood shape	1
96	regular holes along the top & bottom edges	3
97	regular holes along the top & bottom edges, regular holes on both side-seams	2
98	reproduction	3
99	simulation only	1
100	stitch pattern combination	21
101	stitch pattern combination of 2x2 & plain	5
102	stitch pattern combination, area measurement of compressed pattern, hexagon shape	1
103	stitch pattern sample	17
104	T's request, plain stitch pattern	1
105	T's request, plating	1
106	technically wrong	1
107	transfer jacquard	3
108	transfer jacquard, horizontal pattern	2
109	transfer jacquard, vertical pattern	2
110	T's request, special yellow yarn	1
111	tubular shape	1
112	tubular strip in pyramid shape	1
113	tubular strip, jump economizer	14
114	wine bottle shape	1
	Total	**364**

Example/s of similar design steps in each project

Process mapping each project, similar knitwear development steps were identified. These were:

- Each project was initiated by the researcher receiving an email or having an initial meeting. In other words, there was an initiator for each project;

- Samples were ready prior to initial meetings with the designers or commissioners. Therefore, each project proceeded based on what the researcher could produce using the knitting system at that time, not what she was instructed to do; and
- The fabric/garment development for each project proceeded with (continual) customized meetings whenever possible, not by the thrown-over *design specifications sheet* only.

Table 38 lists the similar design steps gathered from each project – that is, Initiation, and Sample preview and Design induction.

There was one exceptional project, which was free from ‘sample preview and design induction’ – ‘Knitwear design using Merino Soul's yarn’. It was impossible to make (design, program, and knit) samples before the initial meeting with the Italian designer because there was no information available on her collection. Instead, the Italian designer’s sample preview and design induction were tried by her showing her look-book and a few signature pieces.

Table 38: Example/s of similar design steps in each project

№	Project	Initiation	Sample preview and Design induction
Pre-1	Pre-design development for 'Design for Comfort'	Being invited to a session at the Department Agriculture and Food Western Australia (DAFWA) to introduce the Shima Seiki WholeGarment® knitting system.	Meeting with one of the project staff who knew the style and preference of each five designer to make samples for pre-selection before individual meetings.
1	'Design for Comfort'	An email from a Design-for-Comfort project staff member to another staff member asking how many fabrics needed to be developed for each designer.	Producing fabrics on the knitting machine much before the first formal training at Shima Seiki in Japan. Pre-sample section for each designer before initial meetings.
2	'Wagin Woolorama Ambassador 2007'	An email from the Design-for-Comfort project staff member asking whether I would be interested in designing the WholeGarment® outfits for the Woolorama Ambassador of the year 2007.	Initial visit of the Woolorama Ambassador of the year 2007. The Ambassador's trying on a few trial prototype garments[12] for me to find out her preference in style, color, design details, and size. Casual photo shoot done for size reference.
3	Cone-shaped artifact	Request from the Design-for-Comfort project staff member asking possibility of creating a 9 meter-long cone-shaped knitted artifact (looking like a jumbo lamp shade) for display at Burswood Casino.	Miniature prototypes of the original jumbo lamp shade completed.
4	Tube sessions 2007 at Curtin University of Technology	Being offered a sessional academic position at Design Department of Curtin University.	Preparation of several base tubular shapes (programmed and knitted).
5	Knitwear design using Merino Soul's yarn[13]	An email from another Design-for-Comfort project staff member announcing the project on the way	Initial visit of the Italian designer with the project staff to discuss the fabric development on the knitting system at DAFWA and to view her look-book and a few signatures.
6	Professional Practicum 390 at Curtin	An email from a second year Curtin student who worked on the tube garment asking for work experience.	18 of miniature WholeGarment® dresses prepared for the students.
7	Dance Performance at the Livestock Updates 2008	Comments from a student who happened to be a dancer on the last day of meeting for 'Chiavazza' project led to some thoughts about wool performance wear. The comments later scheduled to hold the Wooldesk's own dance performance night at the Livestock Updates.	Collecting the tube garments of 2007 from the second year students (now on their final year) for the dance performance night.
8	Tube sessions 2008 at Curtin University of Technology	An email from the head lecturer regarding upcoming tube sessions for the next semester.	Confirmation on previous knit data files of tube garments 2007. Tube garment 2007 on view

[12] The trial prototypes are produced on regular bases to check the embedded body measurements in the knitting system. They can be done with inexpensive yarn or left-over of the 'real' yarn. They are created for the purpose of making customized knitwear.

[13] One exceptional project free from 'sample preview and design induction'

Summary of studio activities

Garment development in this research was based on the body measurement of the size 8 female model and aimed for the creation of unconventional styles with simple tubular forms to demonstrate novel fabric texture. Following the integrated high-fashion knitwear prototype process to *1st sample* production, the researcher selected the stitch pattern first, and then moved onto the garment shape development. She applied the following way to develop 384 all-over texture or partial texture knitted pieces:

For the stitch pattern selection, a stitch pattern or more stitch patterns were chosen from the SDS-ONE® Pattern Library, and then modified exploring the best suitable 'transformation manipulation' which was readily available via the software functions. Modification occurred in any case, none of the chosen stitch patterns for further development or WholeGarment® designs were used as it was.

For garment shape development, the researcher used seven methods to develop 319 WholeGarment® pieces.

Eight different types of pre-registered garment shapes and S•Paint software were used for 319 WholeGarment® designs. In the earlier project, Project 2: 'Wagin Woolorama Ambassador 2007', the pre-registered garment shapes were used almost as they were because there was no need for changes (see Table 13). Therefore, the conventional garment designs were created (see Figure 112). Starting with the Project 3, Cone-shaped artifact, the researcher was at the stage of manipulating the standard garment shape; she later explored the maximum manipulation of the normal garment shapes to create the look of extreme fashion for the Project 5, Knitwear design using Merino Soul's yarn.

Due to the researcher's remote environment from the direct technical support, trial-and-error processes were consequently applied (Popovic, 2004, p. 532) that led to opportunities in each project for new outcome knowledge to be identified. These opportunities for identifying outcome knowledge can be seen in terms of 'breakthrough' experiences that were the driving force for the researcher to move forward. Most breakthroughs of the projects were related to overcoming technical and operational skills except the project 'Tube sessions 2007 at Curtin University of Technology', when the researcher struggled to source yarn rather than resolve technical problems.

The researcher's competency level with the use of the WholeGarment® knitting system increased significantly after she had completed three formal training programs. After the tube session 2007 project, there was no more uncertainty existing within each project. The researcher knew what to expect and what she was doing.

The following table 39 describes findings from analysis of emails and studio activities in whole.

Table 39: Findings from analysis of emails and studio activities

№	Activity (Duration day/s)	Objectives/Aims	Researcher's roles	Activity category	Studio activity state	Number of knitted designs
1	Initial involvement with DAFWA (126)	To develop a potential research project for PhD	Stakeholder	Event		
		To get access to the Shima Seiki WholeGarment® knitting system at DAFWA to support the research proposal				
2	Belmont Designedge seminar (61)	To show seamless knitwear technology 'in action' and explain briefly how to apply designs to utilize this technical advancement in customizing wool knitwear during Belmont Designedge Innovation Festival as guest speaker	Machine operator & speaker	Seminar	Pre-design development for 'Design for Comfort'	18
					'Design for Comfort'	28
					Own design development practice 1	56
3	1st Training at Shima Seiki (33)	To be trained as a knitting machine technician starting with preliminary knowledge of the WholeGarment® knitting machine and basic technical skills	Programmer & Machine operator	Training		
		To be trained as a knitwear designer with understanding and thorough knowledge of SDS-ONE® CAD system	Conventional knitwear designer			
4	1st Technician's visit (5)	To upgrade the CAD system and the knitting machine software to Version A48	Stakeholder	Technician's visit		
		To have a short training on some technical issues in programming and operating the knitting machine	Machine operator			
		To operate the knitting machine following the technical specifications from Shima Seiki	Design consultant & Programmer			

5	Seminar for TAFE students (13)	To show the WholeGarment® knitting technology 'in motion'. To explain briefly how to apply designs to utilize this technical advancement in new knitwear design, customizing knitwear, knitwear production[14]	Machine operator & speaker	Seminar		
6	'Design for Comfort' (169)	To work with five Western Australian designers to develop customized knitted fabrics for them, which were created on the Shima Seiki WholeGarment® knitting machine at DAFWA and also from specially selected WA wool fiber (DAFWA, 2006) for 'Design for Comfort' project which led to the exhibition and fashion show	Design consultant, Programmer, & Machine operator	Project		
7	Dust issue (6)	To identify whether there was a problem in breathing in wool particles or dust from fine micron wool yarn and whether it could cause harm to the knitting machine operator Occupational and safety issue with Shima Seiki	Stakeholder	Issue		
8	2nd Training at Shima Seiki (11)	To be trained as more of a designer-technician who was willing to take the part of programming role	Design consultant, Programmer, & Machine operator	Training		
9	IP situation (141)	To discontinue the research while formalizing the relationship between Curtin and DAFWA with respect to the PhD project.	Stakeholder	Issue	'Wagin Woolorama Ambassador 2007'	15
10	Knitting machine demonstration for students from Narrogin Agricultural College (3)	To set up the knitting machine half way through knitting something to show the machine 'in motion'	Machine operator	Demo		
					Own design practice 2	3
					Cone-shaped artifact	11
11	'Wagin Woolorama Ambassador 2007' (72)	To create WholeGarment® outfits for the Woolorama Ambassador of year 2007	Design consultant, Programmer, & Machine operator	Project	Stitch pattern and garment shape development for Master's	34

[14] For TAFE students, focus was on knitwear manufacturing rather than knitwear design.

12	Cone-shaped artifact (49)	To create a 9meter cone-shaped knitted artifact for display at Burswood Casino	Design consultant, Programmer, & Machine operator	Project		
13	Knitting machine demonstration for Iraq customers of DAFWA (7)	To set up the knitting machine having already half knitted a garment. That way the machine could be restarted anytime and people could watch the machine 'in motion', and also the drop-off of the garment from the machine	Machine operator	Demo		
14	The Bird Flu issue (15)	To be unable to receive a few wool sample cones sourced from the overseas yarn supplier	Stakeholder	Issue	Own design development practice 3	12
15	3rd Training at Shima Seiki (12)	To be trained as a knitting machine technician with intermediate level of knowledge and technical skills on the WholeGarment® knitting machine	Programmer & Machine operator	Training	Master's	57
		To be trained as a knitting machine technician with intermediate level of knowledge and technical skills on the WholeGarment® knitting machine	Design consultant, Programmer, & Machine operator			
16	Sourcing yarn from overseas (163)	To identify a suitable overseas yarn supplier with whom to have a longer term primary yarn relationship due to the discontinuation of yarn and other consumables over the IP issue	Stakeholder	Issue	Tube sessions 2007 at Curtin	64
17	2nd Technician's visit (1)	To upgrade the CAD system and the knitting machine software to A52	Stakeholder	Technician's visit		
		To have a consult and gain advice on some technical issues in programming and operating the knitting machine	Design consultant & Programmer			
18	Seminar for TAFE students (11)	To demonstrate the WholeGarment® knitting technology 'in motion' and discuss its current application to the design industry	Machine operator & speaker	Seminar		
19	Employment and business case at DAFWA (134)	To work out a business plan for the Shima Seiki knitting machine, in other words, to write up a business case to justify creating a position for SY at DAFWA	Stakeholder	Event		

20	Tube sessions 2007 at Curtin University of Technology (57)	To explore applying WholeGarment® knitting technology to students' design practices	Design consultant, Programmer, & Machine operator	Project		
21	Knitwear design using Merino Soul's yarn (61)	To develop fabrics and whole- garments using Merino Soul, a new type of 100% Western Australian Merino wool yarn, using Shima Seiki knitting machine at DAFWA in collaboration with an Italian designer, Bianca Gervasio	Design consultant, Programmer, & Machine operator	Project	Own design development practice 4	32
					Knitwear design using Merino Soul's yarn	57
22	Professional Practicum 390 (49)	To provide the students majoring in fashion and textile design at Curtin University of Technology with a practical and a short-term internship in some aspect of professional art practice	Design consultant, Programmer, & Machine operator	Project	Professional Practicum 390	9
23	3rd Technician's visit (1)	To upgrade the CAD system and the knitting machine software to A58	Stakeholder	Technician's visit	Own design development practice 5	40
		To have a consult and gain advice on some technical issues in programming and operating the knitting machine	Design consultant & Programmer			
24	Dance Performance at the Livestock Updates 2008 (67)	To present tube garments via dance performance at a conference on the evening of July 1, 2008 at The University Club of Western Australia	Design consultant, Programmer, & Machine operator	Project	Dance Performance at the Livestock Updates 2008	14
25	Tube sessions 2008 at Curtin University of Technology (57)	To apply WholeGarment® knitting technology to the students' design practices	Design consultant, Programmer, & Machine operator	Project	Own design development practice 6	18
					Tube sessions 2008 at Curtin	58
					Own design development practice 7	5
					Tube sessions 2008 at Curtin	(58)
					Number of knitted designs in total	**531**

Appendix 6: Typical standard fashion design silhouettes

The triangle

- A-line
- Trapeze
- Trumpet
- V-line
- Y-line
- Wineglass
- T-line

Figure 127: Triangle silhouettes

The rectangle

- Boxy
- Straight
- H-line
- Slim
- Fitted
- Empire

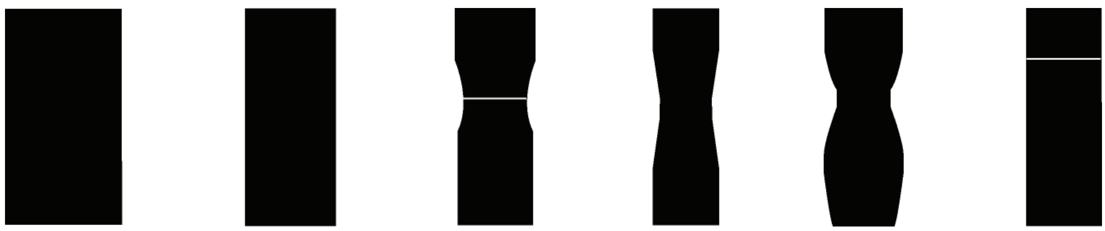


Figure 128: Rectangle silhouettes

The oval

- Barrel
- Balloon

Figure 129: Oval silhouettes

The X-form

- Hourglass
- Princess line
- Fit & flare
- Bell

Figure 130: X-form silhouettes

The hybrid

- Bustle
- Mermaid

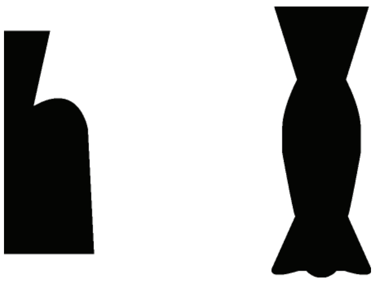


Figure 131: Hybrid silhouettes

Appendix 7: A short course for students in higher education

A more refined short course for students in higher education on computerized seamless V - bed knitting technology was devised as the result of the researcher's experiences in delivering the short courses described in chapter 13. The timeline for this course is shown below in Figure 132.

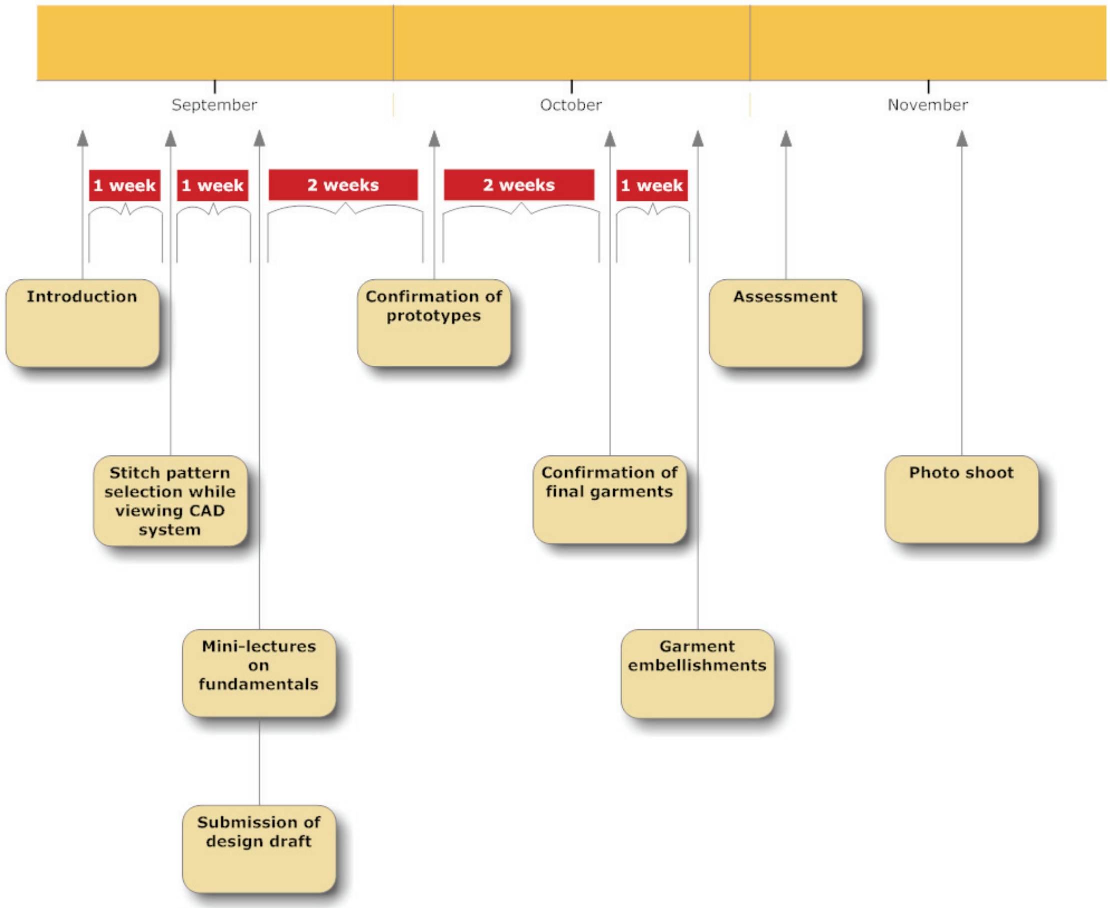


Figure 132: Timeline for introductory short studio-based fashion knitwear design course using computerized seamless V-bed knitting technology

This course model can be used as a workshop, a brief intensive course, for students in the upper level of higher education and adapted to a seminar. It could also be a more formal study, perhaps for postgraduate level students.